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Establishment of an allocated zone for aquaculture (AZA) within the marine spatial planning in Monastir, Tunisia

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Linda Fourdain

This work was carried out at the headquarters of the General Fisheries Commission for the Mediterranean (GFCM) of the Food and Agriculture Organization of the United Nations (FAO) in Rome, Italy, under the direction of Fabio Massa and Aitor Forcada.

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ABSTRACT

The aquaculture sector in the bay of Monastir has grown enormously since 2008 and represents the 46 % of the national production. In this thesis the aquaculture activities and the social, economic and environmental available information were used in order to contribute in the establishment of an Allocated Zones for Aquaculture (AZA) and its management plan for having a sustainable aquaculture development. The environmental data collected showed localised high concentrations of nutrients from the shoreline to the first 10 meters of depth. The environmental monitoring programme (EMP) showed high levels of suspended matters that should be reduced. The production carrying capacity have been estimated and compared to the capacity given. Most farms should review their capacity. The farms production was collected per area and compared to the production carrying capacity and most of the aquaculture facilities could produce over 55.6 – 68.9 % more. The degree of compatibility was estimated and the area of study was categorized as follows: discordant area (where information is not reliable and further analysis is required), moderately compatible area (farms can be located but with limitations) and compatible area (suitable zone for aquaculture). These areas were mapped using a Geographic Information System (GIS). The thesis permitted a first appraisal on the definition of AZA and the areas and topics necessary to be further investigate. The establishment of an Allocated Zone for aquaculture (AZA) in Monastir is still underway.

Key words: AZA, GIS, suitability index, aquaculture, degree of compatibility

RESUMEN

El sector acuícola en la bahía de Monastir ha crecido rápidamente desde 2008 y representa el 46 % de la producción nacional en 2015, En esta tesis se analizaron informaciones de carácter social, económico y ambiental relacionados con la acuicultura. Esto se realizó con el fin de establecer una zona apropiada para la acuicultura (AZA) y su futuro plan de gestión para alcanzar un desarrollo acuícola sostenible. Los datos ambientales recogidos mostraron altas concentraciones de nutrientes entre la línea de costa hasta los 10 metros de profundidad. Los resultados de los monitoreos ambientales de las granjas instaladas mostraron concentraciones elevadas de materiales en suspensión. La capacidad de carga productiva fue estimada y comparada con la capacidad autorizada de cada área de concesión. Esto señaló la necesidad de reajustar las capacidades con las estimadas. Los datos de producción de cada granja fueron colectados por área y comparada con los resultados de capacidad de carga, mostrando que la mayoría de las instalaciones podrían aumentar su producción en un 55.6-68.9 % más. El grado de compatibilidad de la acuicultura fue estimado con el fin de categorizar el área de estudio: Área discordante (donde la información no era lo suficientemente fiable y requiere posterior análisis), área moderadamente compatible (las granjas pueden ubicarse pero con limitaciones) y área compatible (zona idónea para la acuicultura). Estas áreas fueron mapeadas usando un Sistema de Información Geográfica (SIG). Esta tesis ha permitido una primera delineación o aproximación de AZA, la cual está todavía en curso.

Palabras clave: AZA, SIG, índice de idoneidad, grado de compatibilidad, acuicultura.

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ACRONYMS

AMA: Aquaculture Management Area

AMShP: Aquaculture Multistakeholder Platform

ANPE: Agence Nationale de Protection de l'Environnement

APIA: Agence de Promotion des Investissements Agricoles

APIP: Agence des Ports et des Installations de Pêche

AZA: Allocated Zone for Aquaculture

AZE: Allowable zone of effect

CAQ: Scientific Advisory Committee on Aquaculture

CRDA: Commissariat Régional au Développement Agricole

CTA: Centre Technique de l'aquaculture

DGPA: Direction General de la Pêche et de l'Aquaculture (DGPA) of MARHP

EAA: Ecosystem Approach to Aquaculture

EIA: Environmental Impact Assessment

EMP: Environmental Monitoring programme

EQO: Environmental Quality Objective

EQS: Environmental Quality Standard

FAO: Food and Agriculture Organization of the United Nations

GFCM: General Fisheries Commission for the Mediterranean

GIS: Geographic Information System

ICZM: Integrated Coastal Zone Management

IMTA: Integrated Multi-Trophic Aquaculture

INSTM: Institut National des Sciences et Technologies de la Mer Ministère de l'Environnement et du Développement Durable

MARHP: Ministère de l'Agriculture, des Ressources Hydrauliques et de la pêche

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1. INTRODUCTION

1.1. Aquaculture backgrounds

1.1.1. General overview of the aquaculture sector

The global consumption of fish and seafood per capita has increased from 18.6 kg in 2010 to 20 kg in 2014. To supply this demand, the total world seafood and fishery production reached 167.2 million tonnes in 2014, of which 73.8 million tonnes represent the aquaculture production (Table 1; FAO, 2016a). Aquaculture is the fastest developing livestock industry sector (5.8 percent annually and globally since 2006) and has therefore become a necessity to supply this demand. A total of 580 species are farmed all over the world, including aquatic plants and microalgae. The main group of species produced is finfish from inland, followed by the molluscs from marine and coastal areas. Most marine and diadromous finfish are reared in floating net cage in the coast and all their nutrition is supplied by formulated feeds.

Table 1. Global production of main species groups of fish for human consumption in 2014. The production is expressed in tonnes. Finfishes: 362 species. Molluscs: 104 species. Crustaceans: 62 species. Other animals: 6 frogs and reptiles species; 9 aquatic invertebrates. Source: FAO, 2016a.

	Inland	Marine and coastal	Total
Finfish	43 559 260	6 302 631	49 861 891
Molluscs	277 744	15 835 450	16 113 194
Crustacean	2 744 537	4 170 536	6 915 073
Other animals	520 850	372 718	893 568
TOTAL	47 102 391	26 681 334	73 783 725

1.1.2. Aquaculture in the Mediterranean and Black Sea countries.

Furthermore, this trend is also reflected at the Mediterranean and Black Sea regions, in which production has reached 2 337 763 million tonnes in 2013 (Massa *et al.*, 2016). This production reflects the evolution of aquaculture in all the member states of the General Fisheries Commission for the Mediterranean (GFCM) in the area of application (excluding Japan).

Marine aquaculture and brackish aquaculture represent 63.23% of the total aquaculture production in the Mediterranean and Black Sea countries, while freshwater aquaculture is equivalent to 36.76% in 2013 (Figure 1, FAO, 2017a). Mariculture is therefore the most relevant aquaculture activity, both economic value and quantity levels.

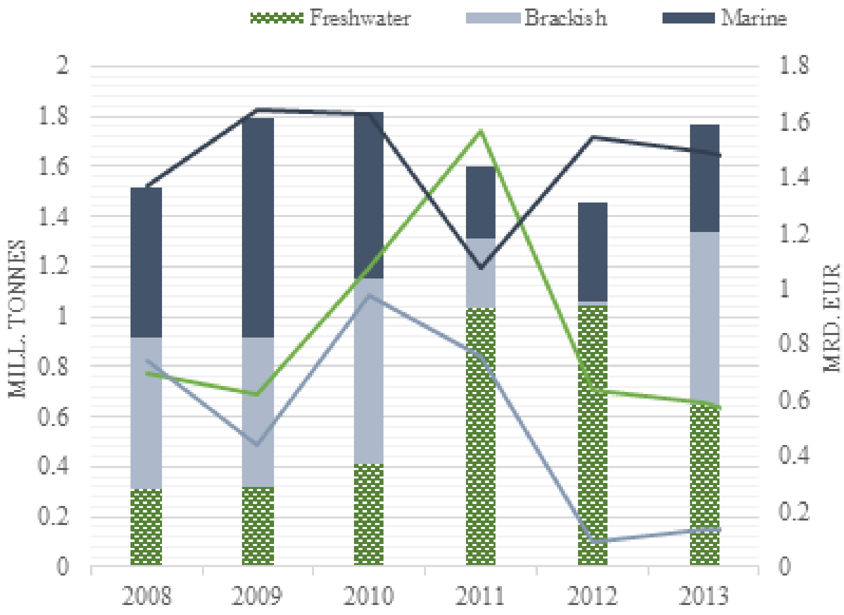

Figure 1. Evolution of the aquaculture production (tonnes and Euros) in the GFCM countries for human consumption. The bars represent million tonnes produced and the lines represent billion Euros. Source database used: SIPAM and FishStat. All environments are represented: freshwater, brackish and marine.

The expansion of mariculture and the fast development of global markets in the Mediterranean, have called on more specialized systems focusing on two main groups of species: fish (82%) and molluscs (16%). Therefore, shellfish and finfish farming predominates in the region and are principally represented by the following species: *Sparus aurata*, *Dichentrarchus labrax*, *Argyrosomus regius*, *Mytilus galloprovincialis*, *Crassostrea gigas* and *Ruditapes philippinarum*.

This increase in production is often associated to impacts in the marine ecosystem. It is important to stress that such impacts depend of the type of aquaculture intensity system and production, species cultivated and farming location.

1.1.3. Potential impacts related to aquaculture

In fact, aquaculture, as well as other industries, can causes diverse impacts affecting social, environmental, economic and landscape structures. As regards mariculture, the unplanned development has generated several concerns issues. Finfish and shellfish farming could cause externalities on the environment, social and economic dimensions in different ways. Shellfish farming is generally considered as more environmentally-friendly as this activity entails a net removal of nutrients from the water. Hereunder is a list of potentially adverse impacts that aquaculture can have, if not properly managed:

Diseases and escapes

Focussing on marine finfish aquaculture, and based on its relationship with the increase of the environmental footprint, one of the issues most comprehensively studied is fish diseases. To deal with a potential outbreak disease and parasites, the farmers use antibiotics or chemotherapeutants (e.g. for parasite control in salmon lice, *Lepeophtheirus salmonis*) (Denholm *et al*., 2002), adversely affecting the environment and other native fish. Furthermore, escapes of cultured stock can throw the ecosystem into imbalances: exotic species predation on native fish, competition for resources, transmission of disease and genetic changes due to the interaction with wild fish (loss of variability by genetic drift, selective breeding and domestication).

Nutrient and chemical discharges

The waste products resulting from the fish farming include uneaten feed, organic matter from net-cleaning (antifouling) and fish faeces. Several studies have demonstrated that there is a modification of benthonic communities located under the cages (Hargrave *et al*., 2008). Besides, one well-known consequence of fish farming in coastal areas is the aggregation of wild fish in the vicinity of the farms, which feed on the non-consumed pellets from the fish cage (Dempster *et al*., 2009). This phenomenon is known as a Fishing Aggregating Devices (FADs) and could be good for fishermen, if managed properly. However, negative effects can occur such as: alteration on the food web, species composition, density of phytoplankton (risk of algal bloom), sediment chemistry and dietary habit. Previous studies have detected compositional side-effects due to this trophic subsidy in the fatty acids profile (Fernandez-Jover *et al*., 2011) and trace element (Arechavala-Lopez *et al*. 2015), that may lead to alterations in the physiology of wild fish targeted by artisanal fisheries (Otterå *et al*., 2009; reviewed by Uglem *et al*., 2014). These negative effect can be minimised by choosing an appropriate area for aquaculture and managing it adequately.

Fishing down and farming up the food web

Regarding global fisheries, catch composition of landings have changed over the years. Therefore, landings have shifted from large piscivorous fishes (e.g. cod and tuna) toward smaller invertebrates and planktivorous species (e.g. sardines, oysters and shrimps). The main reason for this is the overfishing of commercially valuable, bigger and slower growing species, leading to target large quantities of smaller species with less commercial value: Fishing down (Pauly *et al*., 1998). Moreover, feed requirements for some types of species and of aquaculture systems, place a strain on wild fish stocks. The proportion of fish meal supplies used for farming fish has been increasing in parallel with aquaculture growth (Naylor *et al.*, 2000). Farming up the food web has been defined as the growing reliance on the production of high trophic level species (Longo *et al.*, 2015). Besides, the trends related to modern intensive systems of aquaculture link together farming up - fishing down the food web, adding more pressure on smaller and lower trophic level species and worsening the effects in the marine ecosystem caused by fishing down. The anchovy fishery (*Engraulis rigens*) is one of the most representative example of the problems related to farming up and have experienced a series of peaks and drastic falls as a direct consequence of El Niño phenomenon and of the massive fishing effort. These catches are almost entirely used in processing of fishmeal and fish oil (producing approximately 25-30% of world's fishmeal and fish oil), and only a small quantity goes to direct human consumption. Promoting the farming of herbivorous and omnivorous species, or increasing the use of other feed sources could provide a suitable solution that might mitigate this difficult situation. The decreasing use of fishmeal and fish oil for fed-aquaculture is showed in the current trend in using proteins from a different origin other tan fish (FAO, 2016a). Furthermore, the general trend indicates that about 25% of fishmeal is produced with fish processing waste, reducing the use of small fish (World Bank, 2013).

Conflict with other users

In some parts of the world, the lack of adequate coastal zone management and site allocation have led to conflicts among competing users for land and water. The expansion of marine aquaculture could become one constraint for others activities, such as tourism and artisanal fisheries, though the same mechanism apply for aquaculture development in areas where other coastal and marine users predominate (Luque and Martin, 2010). Sometimes, unplanned development of aquaculture has led to the loss of traditional livelihood and alteration of the environment. For example, due to the unplanned development of shrimp farming in countries such as the Philippines, Chile, Ecuador or Honduras, the construction of ponds was an important cause of mangrove loss (Primavera, 1997; Tobey *et al*., 1998). Besides, in some cases, finfish cages have triggered the aquatic ecosystem degradation of sensitive areas, like *Posidonia oceanica* meadow and other marine phanerogams or algae. This may influence the social acceptability of aquaculture and act as a deterrent for a sound industry development.

Aquaculture can have positive effects on the ecosystem, such as restocking of overexploited aquatic population and marine protected areas, and contributing to the seafood production, being a source of high quality fish protein. Indeed, good things have been developed and aren't necessarily known. Throughout the years, many initiatives and endeavours have been made to reduce risk and aquaculture impacts.

1.2. Evolution of the international legal and institutional framework for aquaculture.

With a view to minimizing the potentially adverse effects of aquaculture and to supplying the population with quality, safe and healthy fish and seafood, many initiatives to improve the aquaculture regulatory and institutional framework were carried out by international, regional and supranational organisations such as the United Nations (UN), the Food and Agriculture Organization (FAO) of the UN, the General Fisheries Commission for the Mediterranean (GFCM) of the FAO and the European Union (EU). Having become increasingly involved in aquaculture sustainable development, these organizations held conferences in order to enhance the aquaculture management, adopted several conventions and developed concepts such as the ecosystem approach to aquaculture (EAA), marine spatial planning (MSP) and allocated zones for aquaculture (AZA). The chronological history of this international, regional and supranational endeavour for improving aquaculture management is reproduced hereunder:

1. The United Nations Convention on the Law of the Sea (UNCLOS, 1982) provided a new framework for a proper management for aquaculture and fisheries, giving coastal States rights and responsibilities. The measures of this Convention were the first adopted at international level to avoid the increasing pollution, stock depletion, misuse of marine resource and their negative implications for food security. Article 1 of UNCLOS highlighted the need "to take measures to ensure the conservation and sustainable use of biodiversity […], to identify and take measures for the control of destructive activities". The ecosystem approach concept was introduced in this article as a new scientific method to analyse the influence and the interactions between human activities and environment. It must be emphasized that provisions of this Convention are still used as a framework for marine resources management.

2. Knowing this situation of declining catches, increasing world demand for seafood and potential adverse impacts of aquaculture, FAO Members States has sought the constant improvement on aquaculture management. In this respect, during the Nineteenth Session of the FAO Committee on Fisheries (COFI), held in March 1991, the Members analysed some issues related to avoid and minimize the aquaculture potential risks to cause significant environmentally and socially adverse impacts (FAO, 1991). Therefore, the Committee considered the urgent need of new approaches to fisheries and aquaculture management, taking into account conservation, environmental, social and economic considerations.
3. Subsequently, the International Conference on Responsible Fishing, held in 1992 in Cancun (Mexico) further requested FAO to prepare an international Code of Conduct to address these concerns mentioned above. Thus, the Code of Conduct for Responsible Fisheries (CCRF), was unanimously adopted on 31 October 1995 by the FAO Conference and stills providing a necessary framework for regional and international organizations to ensure sustainable exploitation of marine resources in harmony with the environment. The CCRF is then a basic instrument for coastal management and to ensure a sustainable aquaculture development, specifically Article 9.1 on "Responsible development of aquaculture, including culture-based fisheries, in areas under national jurisdiction" and the Article 9.4 on "Responsible aquaculture at production level" (FAO, 1995).
4. Efforts to strengthen an aquaculture management framework at regional level have also been made in the Mediterranean and Black Sea. In particular, the agreement for the establishment of the GFCM adopted in 1949 and especially Article 5.e outlines that "foster, as appropriate, a subregional approach to fisheries management and aquaculture development in order to better address the specificities of the Mediterranean and the Black Sea" (EU, 2015). This reflects the involvement of the Commission in all aspects of management, in order to enhance its effectiveness support for aquaculture development.
5. Since 2006, the Aquaculture Management and Conservation Service (FIMA) of FAO has been developing a framework for an Ecosystem Approach to Aquaculture (EAA). During the workshop organized with the Universitat de les Illes Balears, from 7 to 11 May 2007, in Palma de Mallorca (Spain), the experts proposed the following definition: "An ecosystem approach for aquaculture is a strategy for the integration of the activity within the wider ecosystem in such a way that it promotes sustainable development, equity, and resilience of interlinked social and ecological systems" (Soto *et al.*, 2008). This definition recaps the ecosystem-based recommendations of the CCRF in 1995 (Article 9). In 2010, FAO prepared technical guidelines on EAA, covering policy, scientific and technical aspects in order to support a sustainable production of aquaculture and use of the oceans and seas (FAO, 2010).
6. Going further on aquaculture management, the United Nations Environmental Programme (UNEP) and Mediterranean Action Plan (MAP) developed in 2008 the protocol on Integrated Coastal Zone Management (ICZM). This protocol provides a common framework for the contracting parties of the GFCM, in promoting and implementing an integrated coastal zone management. It aims to apply different policies affecting the coastal zone, where human activities such as aquaculture, fisheries and tourism coexist alongside nature. Several articles of the protocol can be used as a framework to create a specific zone for aquaculture, taking into account the diversity of marine activities and the fragility of coastal ecosystems and landscapes (UNEP/MAP/PAP, 2008).

7. In line with what has been mentioned above, FAO and the GFCM have adopted an integrated and operational management framework to sustain the value of the marine biodiversity and to allow the sustainable use of the marine area. This integrated framework is called Marine Spatial Planning (MSP), and is an effective process for achieving economic and environmental objectives. Although the concept of MSP started many years ago, it has been used recently in the more crowded coast and seas of European countries as an effective management framework. The United Nations Educational, Scientific and Cultural Organization (UNESCO), its Intergovernmental Oceanographic Commission (IOC) and the Man and the Biosphere Programme (MAB) have developed a practical guide to MSP in 2009 (Ehler and Douvere, 2009). Besides, the FAO published a framework and the necessary steps to achieving a successful MSP implementation within the Regional Commission for Fisheries (RECOFI) (Meaden *et al*., 2016).
8. Once adopted the FAO's Vision and Global Goals in 2009, FAO has reviewed its Strategic Framework 2010-2019 and have concentrated its efforts in striving to achieve its Strategic Objectives regarding aquaculture development. Especially, the Strategic Objective 2 (SO2) "Increase and improve provision of goods and services from agriculture, forestry and fisheries in a sustainable manner", includes also aquaculture sector and highlights the need of ensuring a better management (FAO, 2013).
9. In the same way as for establishing policy and regulatory initiatives mentioned above, the GFCM adopted in 2012 a specific Resolution GFCM/36/2012/1 on Guidelines on Allocated Zones for Aquaculture (Annex 1). This resolution implements a regional strategy for the creation of AZA and takes into account some institutional framework outlined earlier: ICZM protocol, CCRF, EAA, MSP and spatial planning for aquaculture.
10. The United Nations Conference on sustainable development (Rio +20) carried out in 2012, implemented "The Future we want". This highlighted the necessity to promote and enhance more sustainable aquaculture to improve food security. The conference also stressed the crucial role of healthy marine ecosystems, sustainable fisheries and aquaculture for food security and nutrition (UN, 2012).
11. Furthermore, the EU has developed an integrated planning and management approach in response to the increasing demand for maritime spatial spaces for activities such as, oil and gas exploitation, fishing activities, aquaculture, tourism and installation for the production of energy from renewable sources. This management approach, called Maritime Spatial Planning, have been developed in the Integrated Maritime Policy (IMP) of the EU. The aim of the IMP is to support the sustainable development of marine-related activities and it identifies maritime spatial policy as a tool enabling public authorities and stakeholders to apply an ecosystem-based approach. Thus, a maritime spatial planning framework has been established to promote the sustainable development of marine areas, considering both uses of marine resources and maritime economies (EU, 2014).
12. Besides, at the international level, the spatial planning for promoting future aquaculture growth, was adopted during the seventh session of the Sub-Committee on Aquaculture of the FAO Committee on Fisheries (COFI), in 2013. Spatial planning considers the social, economic, environmental and governance objectives of a sustainable development when aquaculture takes place in common properties such as shared waters (FAO, 2014). The selection of the spatial area designated for aquaculture development and careful selection of farm sites are essential to ensure the success and sustainability of aquaculture. These first steps

have to be carried out in accordance with the CCFR and the EAA, thereby spatial planning has become an important process and framework to create an AZA within the MSP.

13. In addition, more efforts have been made at regional level, especially in the Mediterranean and Black Sea (GFCM area of application). In particular, during the Regional Aquaculture Conference carried out from 9 to 11 December 2014, in Bari (Italy), the Blue Growth Initiative (BGI) became an important GFCM goal. By adopting the BGI, the GFCM have the aim to support a more productive, sustainable and responsible fisheries and aquaculture, by improving the governance and participative management of aquatic ecosystems. This initiative also focuses on restoring oceans and seas potential by introducing responsible and sustainable approaches to accommodate economic growth, food security and conservation of aquatic resources (FAO, 2016b).
14. Despite the growing role played by the organizations, more efforts to ensure a better governance and cooperation in aquaculture had to be carried out. The UN therefore adopted in 2015, the Sustainable Development Goals (SDGs). The Goal 14.7 intends to "by 2030, increase the economic benefits to small island developing states and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism" (UN, 2016). Furthermore, the Goal 14.5 was identified as sustainable development priorities for countries on the conservation of coastal and marine areas (Osborn, *et al*., 2015). The concept of AZA is also related to the goal 2 of ending hunger, achieving food security, improving nutrition and promoting sustainable agriculture.
15. Finally, the most recent effort for improving aquaculture management, was conducted by the GFCM, following the thirty-ninth session of the Commission, held in Milan (Italy) in 2015, which discussed and decided to establish a Task Force on a Strategy for the sustainable development of Mediterranean and Black Sea aquaculture (ATF). Furthermore, it is also based on the strategic areas of the GFCM Aquaculture Multi-Stakeholder Platform (AMShP) and has been enriched with the outcomes of other aquaculture projects carried out so far under the GFCM Framework Programme, which is explained below. The first meeting of the ATF, carried out in May 2016 (Naples, Italy), gave a framework and the key elements to establish the aquaculture strategy. During the second meeting, from 7 to 9 November 2016 in Rome (Italy), the Targets and their Outputs to establish a regional medium-term aquaculture strategy have been discussed. Regarding the concept of AZA, it is included in the Target 1 "Build an efficient regulatory and administrative framework to secure sustainable aquaculture growth", and in particular, in the Output 1.2 "Integrated aquaculture in coastal zones", where its implementation must be considered as a priority for the responsible development and management of aquaculture activities in the GFCM area (FAO, 2017b).

As is evidenced by all the endeavour for improving the sustainable aquaculture development mentioned above, the management capacity remains at the central of international and regional attention. Therefore, as one of the most recent concepts developed, the implementation of AZAs has become a crucial point in the regional strategy in the GFCM area of application.

1.3. Justification and objectives of the study

Tunisian marine aquaculture production has continued to grow, from 1250 tonnes in 2004 to over 13230 tonnes in 2015. This production is mainly characterized by finfish marine aquaculture in cages, with more than 6000 tonnes produced in the Bay of Monastir. This increase in production was possible thanks to a series of factors that have had a positive influence, such as:

- Increasing political awareness on the importance of the sector in sharing of the global Tunisian fisheries production supported by fiscal facilitation.
- Improving technologies that permitted the setting of the existing cages and increased interest of the investors towards aquaculture.
- Presence of research institutions and administrative expertise and effort made that facilitated this process.

The cooperation between the GFCM and Tunisia put a particular emphasis on the different aspects regarding the capture fisheries and aquaculture. For what concerns aquaculture, it is worth noting that the Tunisian experts actively participated in activities of the Scientific Advisory Committee on Aquaculture (CAQ) dealing among other with: interaction between aquaculture and the environment; economic, social and environmental indicators; aquaculture multi-stakeholders platforms and statistics for both shellfish and finfish farms. In Tunisia, several pilot actions were implemented in cooperation with the administration, the researchers and the producers within the context of the “Indicators for Sustainable Development of Aquaculture and Guidelines for their use in the Mediterranean” (InDAM project), and addressed the identification of indicators for sustainable aquaculture. Particular cooperation was also held within the context of the launching of the Tunisian aquaculture multi-stakeholders platform.

This study was held within the framework of the Memorandum of Understanding between Tunisia and FAO-GFCM concerning the “Technical assistance on fisheries and aquaculture within the context of the GFCM Framework Programme” and in particular within the task “Development of a strategy according to the sustainable development of aquaculture, within the framework of the national aquaculture multi-stakeholder platform (AMShP) and within the Allocated Zones for Aquaculture”.

With the aim to contribute to the establishment of an AZA in the bay of Monastir, four objectives were addressed:

1. Analyse aquaculture sector in Monastir.
2. Gather and analyse available aquaculture information and data related to environmental, economic, social and administrative levels. Maritime and land uses.
3. Made a first estimation of the degrees of compatibility and production carrying capacity.
4. Delineate the AZA.

1.4. Area of study

1.4.1. Governorate of Monastir

The governorate of Monastir is one of the 24 Tunisian governorates and is located on the central East side of Tunisia (Figure 2). This region is characterized by having a land area of 1,024 km^2, which represents 0.6 % of national territory, with a population approaching 550,000 in 2014. Monastir is part of Sahel region and is located in southern of Sousse and in the northern of Mahdia.

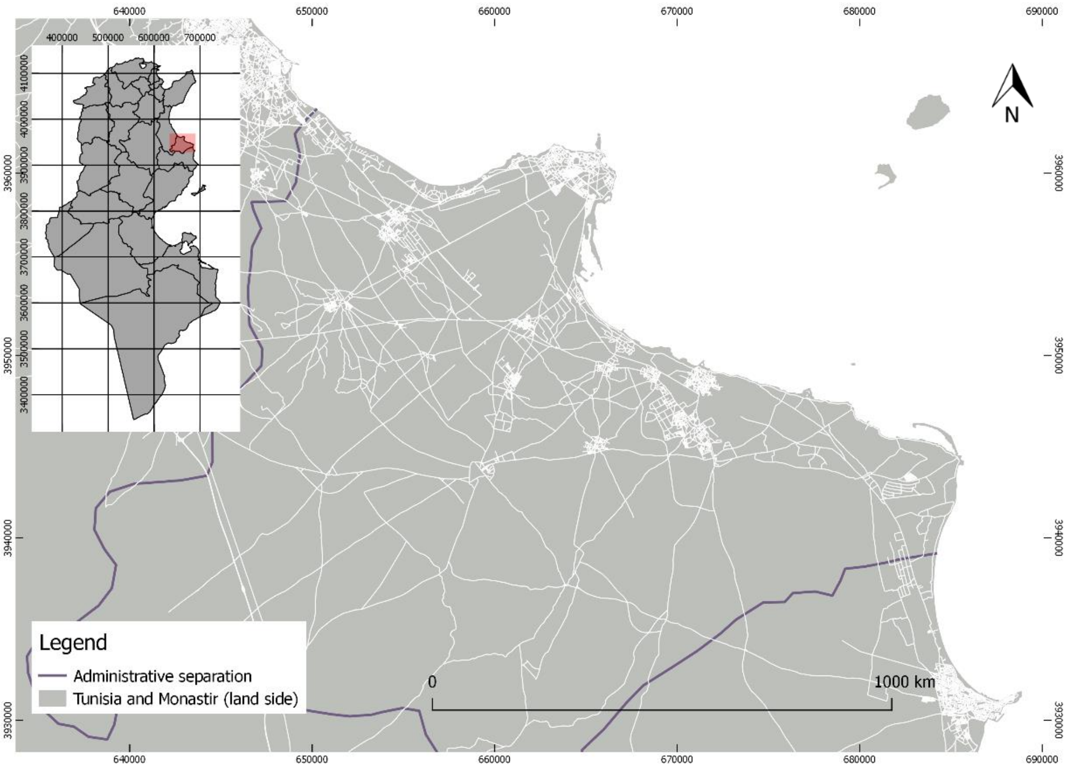

Figure 2: Governorate of Monastir.

The economy is primarily based on agriculture, in particular on the olive growing, covering 86 % of the land area. However, the textile industry is the largest contributor to employment creation, followed by tourism and fishing, including aquaculture. The tourism sector covers the coastal geographical area from the north of the governorate to Monastir's city. Besides, the fishery industry and specifically artisanal fishery, has always been one of the principal sectors. Artisanal fishing grounds are not well specific and defined but are most common from less than 3 nautical miles from the shoreline. The target species are mainly squids, red mullets (*Mullus barbatus* and *M. surmuletus*), common sea bream (*Pagrus pagrus*), octopus and the royal shrimp among others. The types of fishing techniques and gear used are mostly:

- Fishing on all the coast with seines.
- Trammel net and gillnets
- Longlines and pots

1.4.2. Characteristics of the bay of Monastir

The coastline runs for approximately 37 km from Hamdoun river to Bekalta and is located between latitudes 35º37' N and 35º47' N and longitudes 10º45' E and 11º45' E. The bay of Monastir is characterised by two water basins separated by a barrier reef, stretching from Téboulba to Kuriat Island. The depth of the area of study ranges from 0 to 65 meters (Figure 3).

The bay of Monastir has a semi-arid Mediterranean climate marked by hot and dry summers and mild winters with irregular precipitation. According to the Tunisian institute of meteorology (INM, Institut National de la Météorologie), the air temperature ranges between 11.5 ºC in February to 29.7 ºC, with an annual average of 20.8 ºC (from 2008 to 2011).

The following table contains the monthly maximum, minimum and average temperatures of the sea surface in the bay of Monastir. The measurements for the sea surface temperature in Monastir are provided by the daily satellite readings (National Oceanic and Atmospheric Administration, NOAA). The warmest month is August, with temperatures that range between 25.4 ºC and 28.2 ºC, with an average of 26.6 ºC. The coldest month is February, with temperatures that range between 13.6 ºC and 15.6 ºC, with an average of 14.5 ºC.

Table 2. Maximum (max), minimum (min) and average temperature of the sea surface. These temperatures (ºC, degrees Celsius) shows the monthly average recorded throughout the bay in 2016.

Temp ºC	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min	14.3	13.6	13.3	14.6	16.9	19.7	23.4	25.4	24.3	21.9	18.9	16.2
Max	16.8	15.6	16.2	18.1	21.6	25.9	26.9	28.2	27.1	25.3	24.1	19.7
Average	15.6	14.5	14.8	16.1	18.8	22.7	25.3	26.6	25.7	23.6	21.2	18

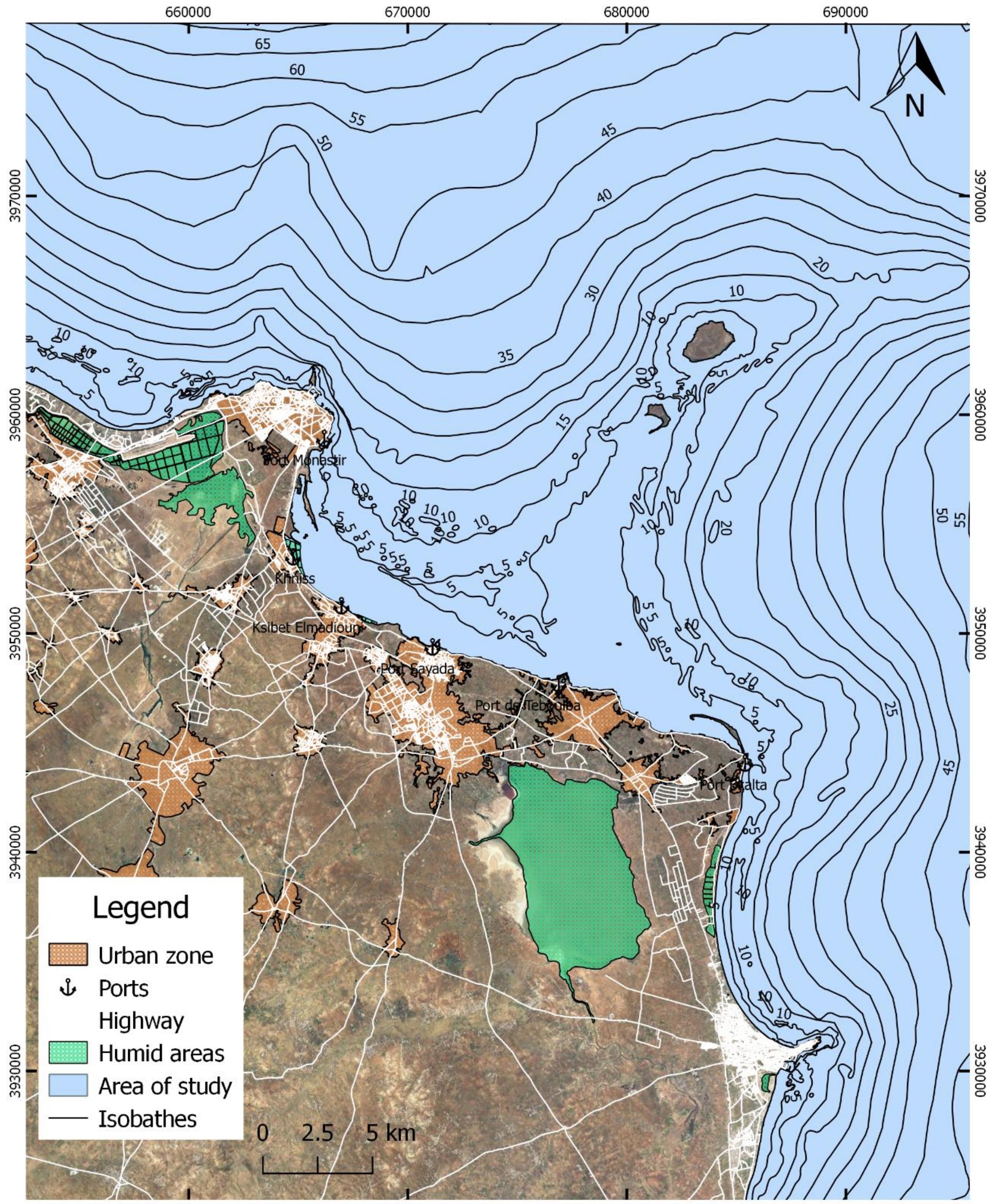

Figure 3. Monastir morphology: urban areas, ports, humid areas (salt mines) and bathymetry. Fishing ports: Monastir, Khniss, Ksibet El Madiouni, Sayada, Téboulba and Békalta.

Marine currents of the bay are relatively low (Figure 4). In particular, the areas with greater speed are located in the north of the bay, around the Kuriat islands and in the barrier reef, with values ranging from 0.1 to 0.27 m/s. The lowest speed is located in the areas within the bay basin, near the coastline and around the barrier reef, with values that range between 0.01 and 0.1 m/s. The current direction follows the coastline morphology from the north to the south.

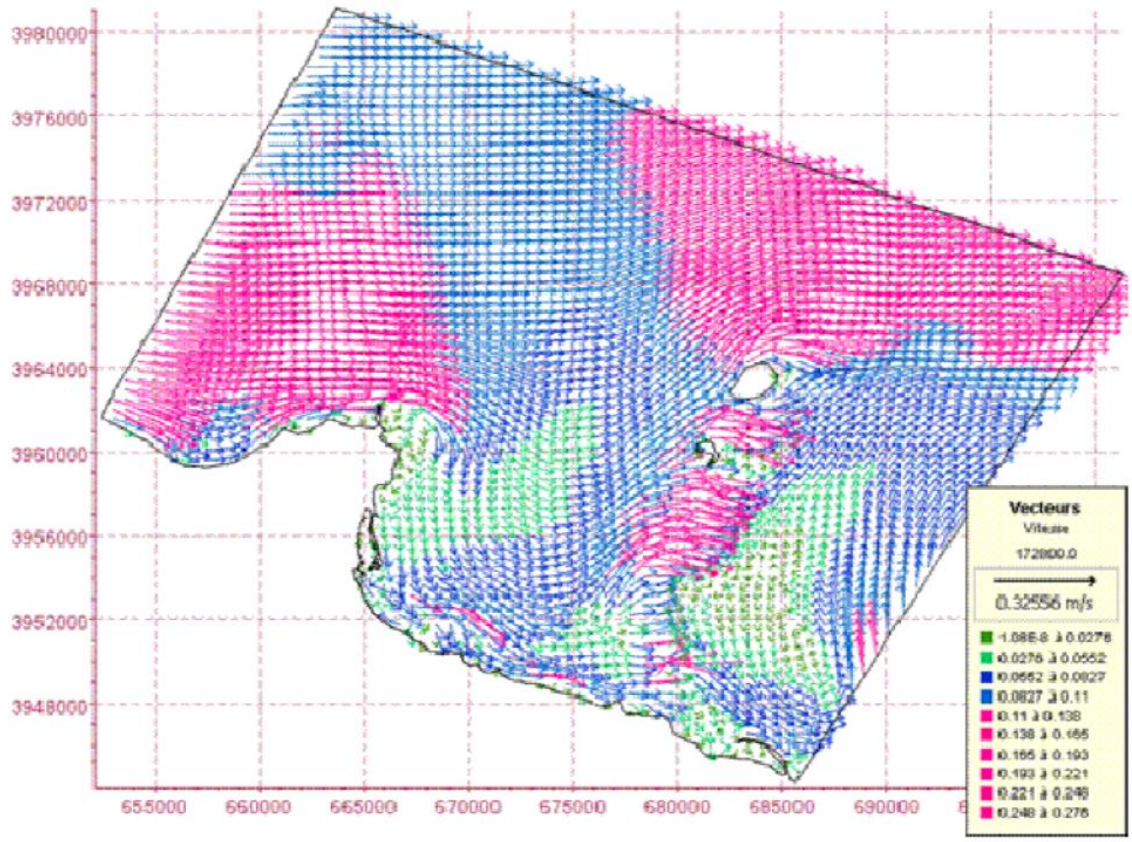

Figure 4. Marine current speed (m/s) and direction of Monastir. Source: APAL, 2010.

According to a study carried out by the Tunisian Ministry of the Environment (APAL, 2010), there are two different ecosystems:

- Coastal littoral ecosystem between 0 and 5 meters is characterised by muddy bottoms with a high level of phytoplankton and nitrophile seaweed (*Ulva rigida*). The proliferation of this kind of seaweed indicates a strong pollution. This region is affected by the accumulation of sediments: anthropogenic origin (urban and industrial waste water discharge) and natural (storm water). The sea water has more or less permanent high nutrient level and localised near the mouth of the river and near waste water discharge points. Ksibet el Mediouni area is the most polluted area due to the bad managed urban zone, textile industry and agriculture.

- Near-shore ecosystem between 5 and 30 meters is characterised by sand and mud bottoms dominated by *Posidonia oceanica* meadow. In some areas of the north-eastern part of the bay, the meadow is more or less disseminated. There is a strong deterioration of the meadow between 10 and 13 meters in front of Ksibet el Mediouni. This deterioration is mainly due to coastal pollution and suspended matter.

1.4.3. Kuriat Islands. Marine protected area

Kuriat Islands are located offshore on the outside of the bay of Monastir and include two islands separated by 2.5 km of water:

- "La grande Kuriat" or "Qûrya El Kabira" with 2.7 km^2 is located on the outer part of the bay. This island is closed to the public due to a military zone located in the middle of the archipelago.

- "La petite Kuriat" or "Qûrya Essaguida" with 0.7 km^2 is located on the south side of the bigger one. This island constitutes a tourist attraction due to their beaches.

The islands are surrounded by *P. oceanica* meadow and their coastal areas are considered as the main nesting sites for protected marine turtles (*Caretta caretta*). This situation has led to the need to create a marine protected area. This marine protected area is not yet established and functional. However, the MedMPAnet project "*Élaboration d'un plan de gestion pour l'aire marine et côtière protégée des îles Kuriat*" (CAR/ASP, 2015) has made a proposal: a reinforced protection area surrounding the islands and a buffer zone around the other, where artisanal fishing will be allowed (Figure 5).

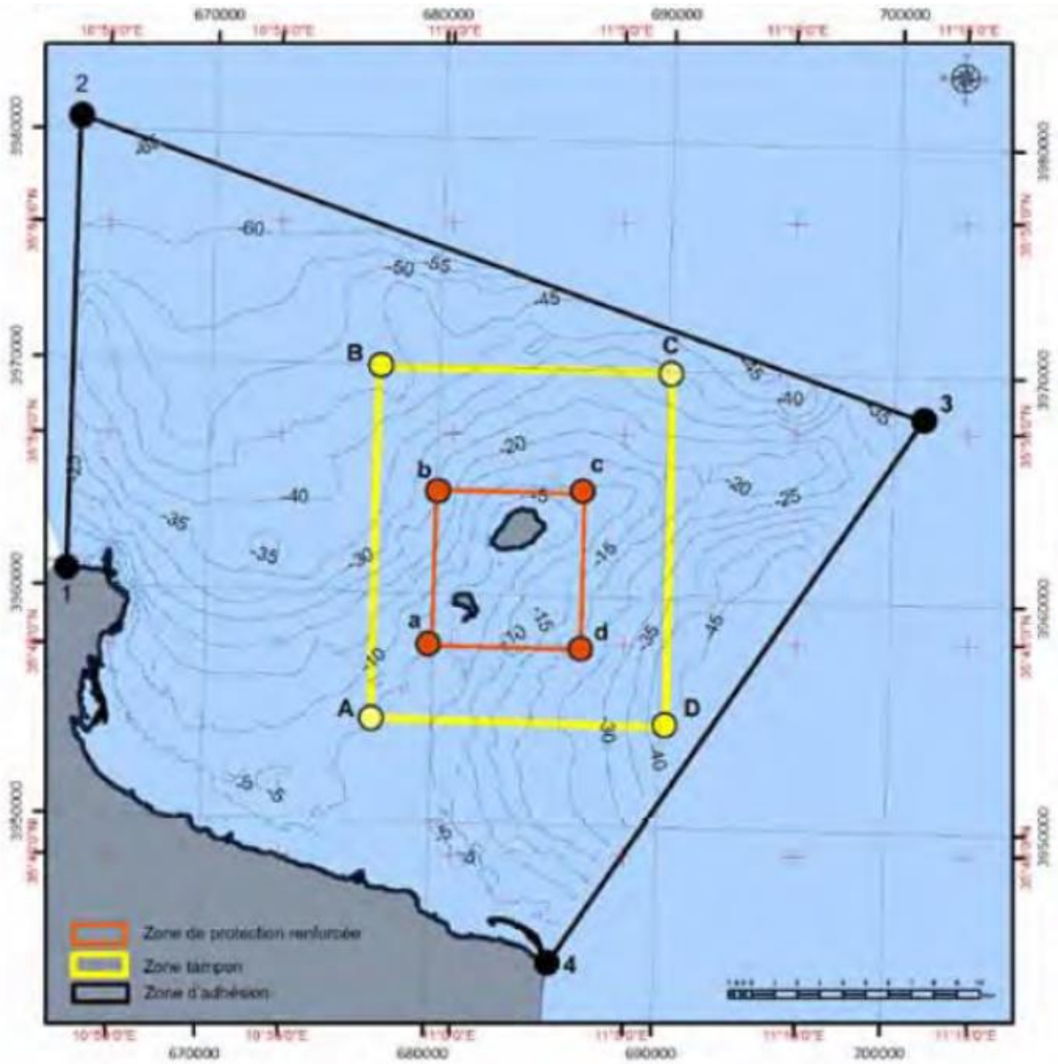

Figure 5. MPA proposal with three different areas: reinforced protection area (red rectangle), a buffer zone (yellow rectangle) and an adhesion zone (black lines). Source: CAR/ASP, 2015.

1.4.4. Aquaculture in Monastir

1.4.4.1. Aquaculture production

Tunisian aquaculture activities have increased considerably during the past decade, starting from 1,250 tonnes in 2004 up to 14,231 tonnes in 2015, for whom 6,575 tonnes have been produced in the bay of Monastir. This is a specialized area in growing up the European seabass and gilthead seabream in floating cages, therefore it has become the most productive aquaculture area in Tunisia (46% of the national production). The political leadership offering tax concessions with a view to encourage to promote the aquaculture investments is one of the factors that has contributed positively to its development. Another positive factor is the effort done by Research Institutes and Administrative Agencies allowing a further technological development of this sector. Additionally there are training institutions 'for technicians, divers and engineers' that assist the processes of creating aquaculture projects.

The following table (Table 3) brings together the production data collected in 2015 at the national and regional levels, of fishing and aquaculture, both broken down into subtypes. The aquaculture is the second most important activity in the area and has the highest growth rates since 2008 (Figure 6).

Table 3. Catch data of different types of fishing and aquaculture production in 2015 (Monastir and Tunisia). Volume in tonnes.

Production (t)	Monastir	Tunisia
Fishing	21536	116410
Artisanal	1911	31761
Small pelagic	19241	58806
Bottom trawls	341	27045
Pelagic trawls	10	
Tuna	33	-
Aquaculture	6575	14231
Sea bream and sea bass	6575	13018
Fresh water	-	1205
Shellfish	-	162
Shrimp	-	2
Seaweed	-	3

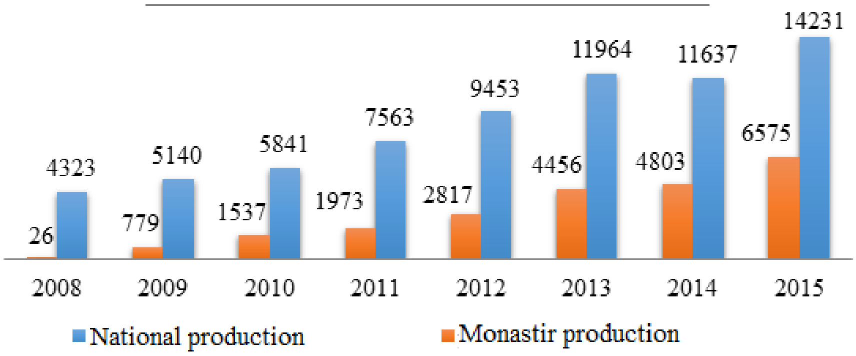

Figure 6. Evolution of the aquaculture production from 2008 to 2015 in tonnes, both in Tunisia (blue) and Monastir (orange).

Fishery and aquaculture products apparent consumption was 11.8 kg/inhabitant in 2015. It should be noted that the aquaculture products (seabream and seabass) are consumed mainly by the local population. In respect of the aquaculture image the consumers require a better taste and quality of the product. Aquaculture is frequently criticized as having a negative impact on the environment.

There is only one Tunisian company able to export seabream and seabass. The main issue to export aquaculture products is the competitivity of other Mediterranean countries, mostly from Turkey (seabass) and Greece (seabream). The seabream (100 tonnes in 2015) and seabass (87 tonnes in 2015) exportation are mainly destined to surrounding countries like Algeria, Libya and Italy among others.

1.4.4.2. Species reared and production system

Seabream (*Sparus aurata*) and seabass (*Dicentrarchus labrax*) are the largest species produced in floating cages in Tunisia which represents over 80% of the aquaculture production. The national seabass and seabream production is 13,018 tonnes in 2015, of which 2,213 tonnes correspond to seabass and 10,805 tonnes to seabream. These two species also represent nearly all the Monastir aquaculture production (51% of the national production). The meagre (*Argyrosomus regius*) is grown in some of the zone cages but in smaller quantities (Figure 7).

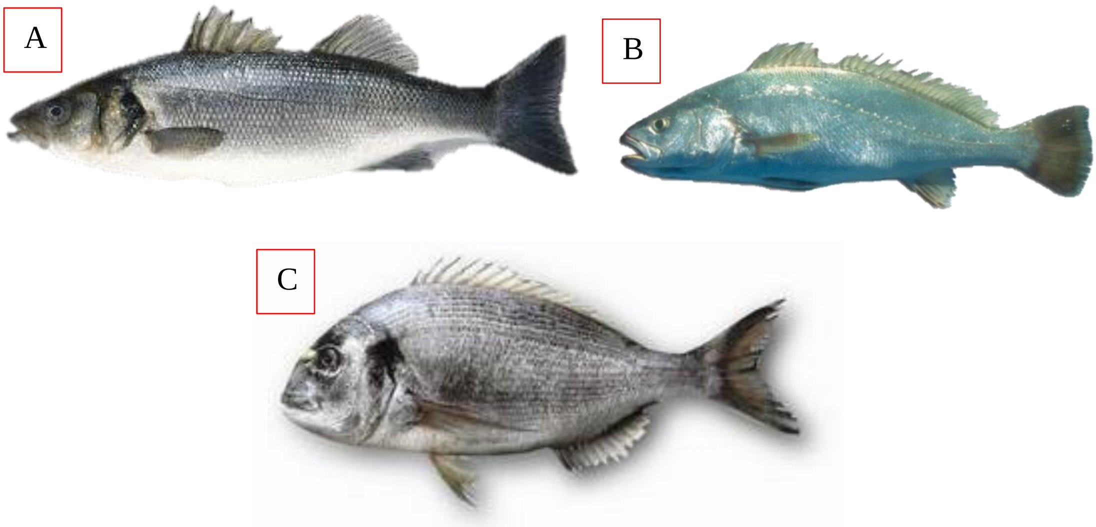

Figure 7. Species reared in Monastir: A. Dicentrarchus labrax. B: Argyrosomus regius. C: Sparus aurata.

1.4.4.3. Factors affecting aquaculture economic development: juvenile production and feed.

An important fact is the national low production of juveniles. In 2015 the two fingerlings producing companies (Aquaculture tunisienne and Sud Aquaculture Tunisie) reached 15 million of fingerlings representing the 17% of feed needed to supply the farming activity (seabream and seabass). The rest of required fingerlings (71 million of fingerlings) to provide the local needs are imported from the northern Mediterranean countries (Spain, France, Italy, among others). The economic sustainability and the possible improvement of the competitivity will mainly depend on the juvenile production. This is because 83% is imported and their prices depend on the external market, covering more than half of the total of the seabream and seabass production cost and has a direct impact on the sales price evolution.

Another factor affecting the economic sustainability of the area is the feed import costs. In 2015, 35,708 tonnes of feed were consumed of which 8,708 were manufactured in Tunisia (24%). So.Tu.PAP (Société Tunisienne pour la Production des Aliments des Poissons) is a feed producing company in Monastir. This company just provides to a group of associate growers: FA_1 and FA_2 (Nakbi group). The companies which import the fish meal (27,000 tonnes) are Aller Aqua (danish), AquaFauna (USA), Biomar SAS (France), INVE Technologies nv (Belgium), Le Gouessant Aquaculture (France) and Skretting Italie (Italy).

1.4.4.4. Tunisian institutional and legislative framework for aquaculture

The administrative governmental body responsible for the aquaculture sector is the Ministry of Agriculture, Water Resources and Fisheries ("Ministère de l'Agriculture, des Ressources Hydrauliques et de la pêche", MARHP). The Ministry has the aim of implementing an adequate framework for aquaculture development and for a better promotion of the sector. For this purpose, the Ministry is in charge of making plans and strategies, to support the exporting efforts by further developing their position in international market and new potential markets. The Ministry is divided in two technical services for the aquaculture sector: Directorate-General for Fisheries and Aquaculture ("Direction Générale de la Pêche et de l'Aquaculture", DGPA) and Directorate-General for Veterinary Services ("Direction Générale des Services Vétérinaires, DGSV") (FAO, 2005).

The DGPA is responsible for making plans and strategies related to aquaculture and fishery development, evaluating investment opportunities and risks in aquaculture industry, and designing incentives and technical support. Also, the DGPA has the responsibility to promote international cooperation projects, such as the agreement between the GFCM and Tunisia on the establishment of an AZA in Monastir.

The DGSV has the responsibility to define the strategies, programmes and sanitary control guidelines, related to animal diseases, health protection, sanitation, and product quality. Furthermore, the DGSV has to deliver official health certificates, with the aim to ensure the product quality before it is distributed and to monitor the quality of product of animal origin, both in importation and exportation

Regarding the legislative framework the law No. 94-13 of 31 January 1994, is the primary legislation governing fisheries and aquaculture sectors in Tunisia. The Articles 1 and 2, highlight the organization of fishing effort, the rationalization of the exploitation to preserve the environment and the harvested species; and also related to aquaculture facilities at sea.

Licensing procedures require prior authorization of the Ministry (MARHP) in charge of fisheries to be able to develop any aquaculture project. It stipulates that the authorization can only be granted to:

- Natural persons of Tunisian nationality.
- Public establishments and national enterprises.
- Legal persons, the capital of which is wholly owned by natural persons of Tunisian nationality.
- Legal persons who:
    - Should be legally constituted in accordance with the laws in force and must have their head office in Tunisia. Having their capital representing not less than 34% held by natural Tunisian persons.

- have their Executive Board, management or surveillance, mainly constituted by natural Tunisian persons

1.4.5. Aquaculture facilities

There are 13 aquaculture companies allocated in the bay of Monastir (Figure 8). Regarding confidentiality issues, aquaculture facilities were renamed, throughout the study, according to the following codes[1]: FA_1; FA_2; FA_3; FA_4; FA_5; FA_6; FA_7; FA_8; FA_9; FA_10; FA_11; FA_12; FA_13 (Table 4). The first to settle down were FA_1, FA_2 and FA_8, and the last were FA_7, FA_5 and FA_13. The biggest licensing and beaconing areas installed belong to FA_8 (Figure 8) and FA_10 has never produced.

Table 4. Aquaculture companies in Monastir (where FA_: Farms; 1 to 13: number assigned to each farm).Capacity given by the competent authorities in tonnes. Licensing area in hectares. Creation date for each company. Number of cages per licensing area with their diameter (in meters). Home ports.

Farms	Capacity given (t)	Licensing area (ha)	Creation date	Cages	cage diameter (m)	Home port
FA_1	1300	45	2008	64	1 Ø 22	Monastir
					4 Ø 29	
					59 Ø 25	
FA_2	1700	36	2009	60	52 Ø 25	
					8 Ø 22	
FA_8	1000	80	2009	24	Ø 22	Téboulba
FA_3	1000	32	2010	20	Ø 25	
FA_4	3000	69.9	2011	44	4 Ø 40	
					40 Ø 25	
FA_8	1650	45	2011	36	4 Ø 25	
					32 Ø 22	
FA_7	2500	45	2015	-	-	
FA_9	480	45	2012	26	20 Ø 22	
					6 Ø 29	
FA_5	400	30	2015	19	Ø 25	
FA_11	1500	45	2013	24	Ø 25	Békalta
FA_13	1080	36	2015	-	-	
FA_12	1600	24	2013	28	Ø 25	
FA_10	-	-	2009	-	-	

[1] For the sake of privacy and the purposes of this study the name of the farms are not indicated and are replaced by a code.

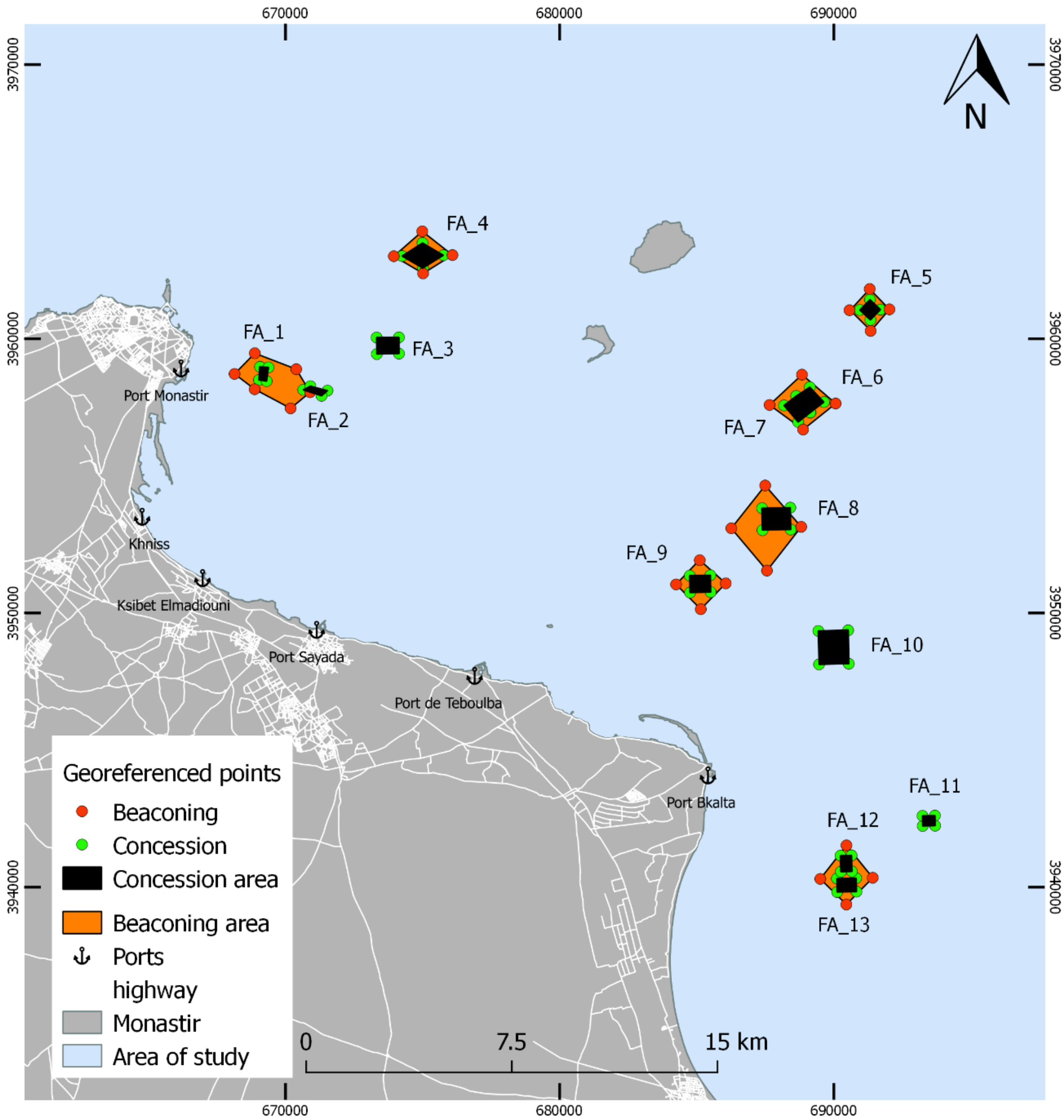

Figure 8. Location of the aquaculture facilities in the bay of Monastir. Farm licensing or concession area (black rectangle and green points), beaconing area (orange rectangles and red points) and aquaculture home ports.

There are six fishing ports in Monastir (Figure 8), of which three of them are also aquaculture home ports: Monastir, Bekalta and Téboulba (Table 5).

Table 5. Farming boats and aquaculture work force per ports in 2016.

Ports	Farming boats	Aquaculture work force
Monastir	8	88
Téboulba	18	198
Bekalta	8	88
Total	34	374

1.5. Allocated zones for aquaculture

1.5.1. AZA definition

It is essential to realize a spatial analysis before the establishment of an aquaculture facility with the aim to avoid potential conflicts between users, negative impacts to the environment and to ensure a sustainable aquaculture development. For this purpose, many management concepts have been developed such as Aquaculture Management Areas (AMAs) and AZA. FAO defined AMAs as a "geographical water bodies or areas where all the aquaculture operators agree (coordinate and cooperate) to certain management partices or code of conducts for the area" (Aguilar-Manjarez *et al.*, 2017).

AZA is defined as a "system enshrined within the wider ecosystem relations and that intrinsically involves the performance of different processes such as identification, study, selection and spatial analysis in order to obtain an area dedicated to planning, management and best practices in aquaculture" (FAO, 2017c). AZA should be developed within the maritime public domain. The planning and decision-making have to be defined by the administration and policy makers. This management tool can facilitate licencing procedures and therefore, aquaculture development.

The identification of AZAs shall also be based on the best social, economic and environmental information available in order to prevent conflict among different users and for an increased competitiveness, shared costs and services and ensured investments.

1.5.2. AZA implementation stages

Several stages have to be taken into account with the aim to establish an AZA in a given area such as Monastir:

1. <u>Analysis of the aquaculture sector in the study area</u>: location of aquaculture facilities, their production and species reared.
2. <u>Analysis of the aquaculture legal framework and identification of the stakeholders involved</u>: licensing procedure, space occupation and uses, health monitoring and environmental protection. Competent authorities and government agencies involved.
3. <u>Spatial analysis</u>: delimitation of the study area, digital ortho-photography of the area and other georeferenced maps.
4. <u>Information and data collection</u>: determine all the environmental, administrative and socio-economic parameters needed.
5. <u>Description of the socio-economic context</u>: to avoid socio-economic conflicts.
6. <u>Establishment of criteria and factors to prepare the spatial analysis</u>.
7. <u>Pre-selection of AZA and production carrying capacity of existing farms.</u>
8. <u>Environmental analysis:</u> water quality and environmental analysis of the preselected area.

9. Carrying capacity: environmental and physic carrying capacities
10. Technical documents in support to the establishment: biological report, production plan, Environmental impact assessment, Environmental Monitoring Programme and economic and financial report.
11. Integration of AZA in the legal framework.

1.5.3. AZA monitoring

The AZA should be accompanied by a monitoring plan and an environmental impact assessment (EIA) (Figure 9). The EIA is defined as "a set of activities designed to identify and predict the impacts of a proposed action on the biogeophysical environment and on man's health and wellbeing, and to interpret and communicate information about the impacts, including mitigation measures that are likely to eliminate the risks. Usually it is carried out by three parties, the developer, the public authorities and the planning authorities" (FAO, 2017c).

The EIA process should be done before and during the aquaculture activity and an allowable zone of effect (AZE) for each farms have to be define. The AZE is a fixed area around and beneath the sea cages, either sea bed and water column, where aquaculture activity can affect the ecosystem and the environmental conditions (Sanchez-Jerez *et al.*, 2016). The environmental monitoring programme (EMP) is a tool that ensures the sustainability of the aquaculture activities. This tool have to be defined during the implementation of an AZA and should be mandatory to maintain, regulate and monitor water quality and to identify potential aquaculture impacts. For this purpose, environmental quality Standard (EQS) have to be defined by regulation to mark allowable concentration of different chemical parameters, specifying the maximum and minimum permissible ranges for each parameter. These limits have to be considered and established within the environmental quality objective (EQO) defined by the legislation, being able to harmonized a regulated framework to preserve water quality status around sea cages.

The EMP should be flexible and adaptable according to farming system, species and production levels. The EMP should be done outside the AZE (minimum two sampling stations) by the competent authorities and inside the AZE (four sampling stations) by the aquaculture company. The sampling stations should be located up and down the current direction, one of them under the cages and all of the water monitoring variables should be collected at three different layers (surface intermediate and deep). The variables that should be analysed are:

- **Water monitoring**: Temperature, salinity, turbidity, dissolved oxygen, chlorophyll a, pH, total suspended matter and particulate organic matter.
- **Sediment monitoring**: Macro-benthic community, visual inspection, redox potential, sulphide, organic matter, pH, total organic carbon, total nitrogen, total phosphorous, gas bubbles and litter present on the seabed in the vicinity of the farm.

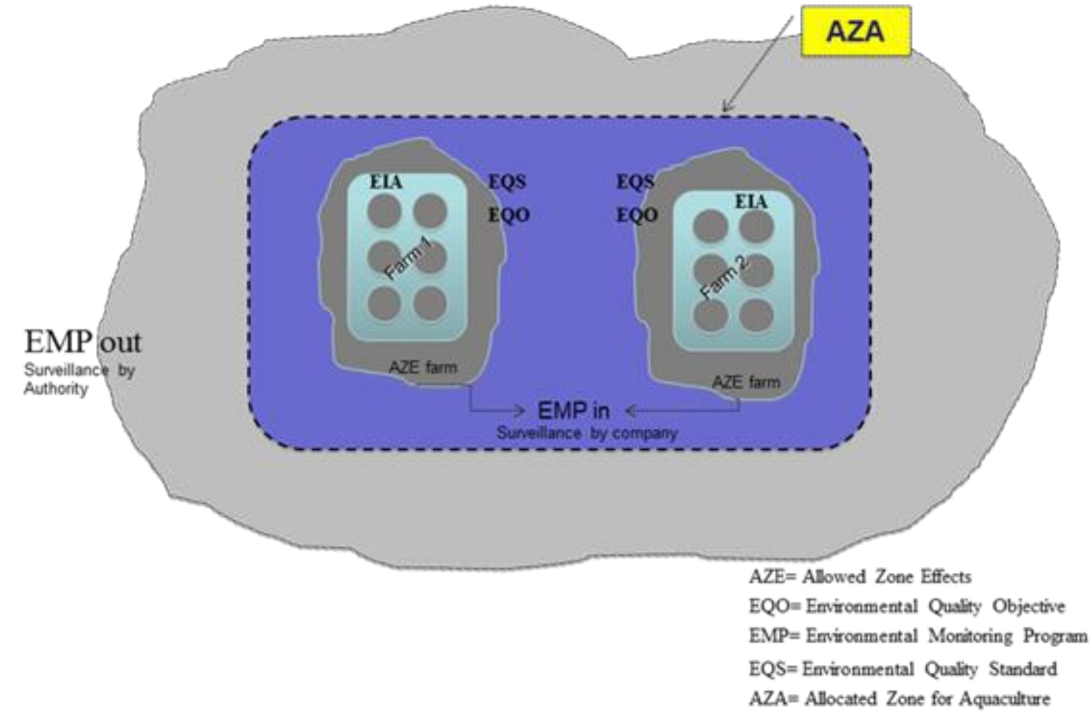

Figure 9. Different zonation related to AZA for management proposals. Copyright: Jose Carlos Macias. AZE: Allowed Zone Effects. EQO: Environmental Quality Objective have to be defined by the legislation. EMP: Environmental Monitoring Programme. EQS: Environmental Quality Standard. AZA: Allocated Zone for aquaculture.

1.5.4. Geographic information systems (GIS)

An integrated spatial representation of the information and data is necessary to understand and define which areas are suitable for the sustainable aquaculture development and to delimit correctly the AZA in the bay of Monastir. This requires a management tool able to perform a spatial representation and an ongoing follow-up and update of information.

Geographic information systems have become increasingly important to aquaculture site selection since its introduction in the late 1980. GIS is particularly useful as a management tool, allowing simultaneous data and information processing and becoming a highly suitable tool in aquaculture site selection and planning projects (Valavanis, 2002).

A geographic information system integrates hardware, software and data for capturing, managing, analysing and displaying all forms of geographically referenced information. This system allows to view, understand, interpret and visualize data and patterns (ESRI, 1998). In particular, GIS are designed for use at different scales, enabling to study specific information of an area.

Different types of information can be integrated in the software: cartographic data (map form), photographic interpretation, data collected by satellites (land use, farms location, and urban zones), remote sensing and data or information in tables.

There are two types of GIS file or shapefile formats (IUCN, 2009):

- Raster formats: information and data is stored within a cell or pixel and is usually used for elevation or satellite information. This type of model is useful for describing geographical objects with diffuse boundaries, such as, nutrients dispersal or currents.

- Vector formats: In this type of format, real entities can be represented by polygons, lines or points and is usually used to define and delimiting protected areas, areas of influence, roads etc.

Geographic information systems enable the enhancement of existing environmental data by incorporation of specific data to the needs of aquaculture sector. It allows the incorporation and analysis of environmental, economic, social and administrative parameters.

2. MATERIALS AND METHODS

In order to contribute in the definition of the AZA in the area of Monastir, the study was based on the data gathered during two field missions in Tunisia, the construction of data base where data have been stored, definition of data modelling framework, and GIS application.

The data collected were further analysed in order to assess the degree of compatibility of aquaculture activities with the economic and environmental condition by the use of model applied by Del Castillo y Rey and Macías (2006) in the definition of AZA in the region of Andalucia.

Finally, the carrying capacity in terms of production were assessed by the application of the model identified by Karakassis (2013) and based on the production data were analysed in order to compare them and to determine the possibility of improving farms production.

2.1. Information and data collection

2.1.1. Field missions in Monastir

To undertake this study, two field missions were done: the first one was conducted from 14th to 18th November 2016 and the second one from 9th to 13th April 2017. Collecting data and gathering information needed were main objectives of these missions with the aim to establish an AZA in Monastir.

<u>Missions' framework.</u>

The missions were performed within the framework of the Protocol of Agreement between the government of the Republic of Tunisia and FAO-GFCM on behalf of the GFCM concerning the project: "Technical assistance in fisheries and aquaculture" in the context of the GFCM Framework Programme, and in particular within the task "Development of a strategy according to the sustainable development of aquaculture, within the framework of the national aquaculture multi-stakeholder platform (AMShP) and within the Allocated Zones for Aquaculture".

Under the general coordination of the Tunisian Government (via the MARHP) and of the Governorate of Monastir, the missions aimed to meet the administrative and research institution officers and farmers in order to prepare a planning for the implementation of an AZA in the bay of Monastir and consistent with the *GFCM Resolution GFCM/36/2012/1 on Guidelines on the establishment of Allocated Zones for Aquaculture* (Annex 1).

<u>Attended meetings and developed activities.</u>

During the missions, several meetings were held with the counterparts and stakeholders involved (Annex 3):

- <u>Research institutions, trade union</u>: Union tunisienne de l'agriculture et de la pêche (UTAP), Institut National des Sciences et Technologies de la Mer Ministère de l'Environnement et du Développement Durable (INSTM), Centre Technique de l'aquaculture (CTA).
- <u>Governmental institution and non-governmental organization</u>: Direction General de la Pêche et de l'Aquaculture (DGPA) of MARHP, Agence Nationale de Protection de l'Environnement (ANPE), Agence des Ports et des Installations de

Pêche (APIP), Commissariat Régional de Développement Agricole (CRDA) and Notre Grand Bleu (NGB).

- Aquaculture multi-stakeholder platform: Monastir Regional Commission for Aquaculture (MRCA).
- Aquaculture producers and fishermen.

The meetings of the first mission had a descriptive approach, by focusing on the status of aquaculture in the bay of Monastir. In collaboration with the stakeholders involved, the meetings touched upon the aspects related to challenges, constraints and priorities of aquaculture development in the bay of Monastir. During all meetings, the travellers devoted a particular attention to informing the different stakeholders on the GFCM Resolution *GFCM/36/2012/1* mentioned above, in order to explain the implementation of the AZA.

The second mission was the follow up of the previous mission and was aimed in continue the technical support and collaboration between GFCM-Tunisia. The topics dealt with included the status of farms allocation and their environmental monitoring system. Another issue stressed were the need to gather more information and data to complete the preliminary analysis of the area. Besides, two seminars were carried out by two GFCM experts on “the veterinary control and product quality” and on “AZA and carrying capacity”. Both seminars were attended by the experts of INSTM and CTA (marine biologists and veterinaries) and representatives of local authorities. One training on FARM software was also attended by representative of the artisanal fishery, aquaculture producers and aquaculture experts.

The field visits conducted during the missions included:

- Field visit at the farms. FA_1, FA_4 and FA_3 were visited during the first mission. During the second one, other farms located in the southeast of Monastir were visited: FA_12, FA_8, FA_9 and FA_6.
- Technical visit. Field visits were carried out at a handling centre of FA_12 in Bekalta and at fish meal production company Société Tunisienne de production d’aliment de poisons d’élevage (So.Tu.PAP), in the industrial zone Neopark Sahline.

2.1.2. Construction of the database

The selection of sites for aquaculture constitutes a technical procedure aimed at establishing an AZA. To this end, a sectoral and spatial analysis is absolutely indispensable (IUCN, 2009). All the technical-administrative and environmental data must be studied in detail in order to specify the priorities to take into account. The most important parameters to analyse will depend directly on the characteristics of the area, on the type of aquaculture developed and to be developed, and on the time available.

A specific survey (Annex 4) was conducted with all the information needed as socioeconomic, governance and environmental indicators. However, as the survey have not been answered, these indicators have not been taken into consideration.

Besides, environmental, physicochemical, administrative, social and economic information and data needed to delineate the AZA in Monastir, are detailed in the Annex 5. Furthermore, most data should be georeferenced, however, must of the information collected was on paper without georeferencing. To use it, all the information was digitized and georeferenced. Some information was already in digital format and georeferenced. The level of difficulty of the interpretation and construction of the mapping will depend on the level of information provided and on the way the information is provided.

2.1.2.1. Basic information

The basic information describes the study area with some of the following parameters:

– Coastline
– Wetland
– Bathymetry
– Land-based structures
– Urban areas

For this study, these parameters were collected from different sources: governmental institution and OpenStreetMap.

2.1.2.2. Administrative parameters and land uses

The occupation of the space and allocation of the farms in the area of the bay of Monastir is the main topic of attention of the local authorities and of some stakeholders. This situation is generating some disputes among the different users over space resource availability. Conflict at port level occurred also in the utilization of the space for the maritime navigation.

– Marine protected areas
– Emissaries
– Traditional fishing areas
– Port areas
– Maritime routes
– Industrial zones
– Licensing and beaconing area for each existing farm

For this study, these parameters were collected from OpenStreetMap, research institutions and fishermen.

2.1.2.3. Social and economic parameters

The interferences between aquaculture and other users mentioned above, have created social acceptance problems. These problems are directed related with economic growth. Due to the scarcity of information available regarding the social and economic dimensions, a minimum number of parameters related to aquaculture were selected:

– Employees
– Production per farms
– Home port
– Tourist area
– Availability of inputs

For this study, these parameters were collected from OpenStreetMap and governmental institution.

The real production reached by farms in 2016 was not detailed by each farm: the real production was grouped by zones (Monastir: includes FA_1 and FA_2; Téboulba: includesFA_8, FA_9, FA_3, FA_4, FA_6, FA_5 and FA_7; Bekalta: includes FA_11, FA_12, FA13).

2.1.2.4. Environmental parameters

This type of information is important to understand the natural surroundings and their value in order to assess potential effects on the sea cages and the technical and biological feasibility (IUCN, 2009).

- Temperature
- Currents speed and direction
- Oxygen
- PH
- Chlorophyll
- Nutrients
- Bottom type
- Turbidity and suspended matters

Most data that should have been taken into account, were not used in the establishment of the AZA (such as current speed and direction), due to the scarcity of information. For this study, the parameters were collected from another study realized in the same zone (Mzoughi, 2012). The bottom type was collected from a predictive habitat map (EuSeaMap, 2016).

2.1.2.5. Data aggregation level

With a view to analyse the aquaculture sector, to define the AZA and to calculate the carrying capacities, information and data were required. All the information and data needed must be identified specifying the appropriate spatial and temporal context: spatial and temporal dimensions should be defined with the aim to obtain a consistent database with the possibility to update them.

SPATIAL AND TEMPORAL DIMENSIONS	DEGREE OF DETAIL AND FORMAT
Spatial replication: required to obtain a complete overview of the real situation. Example: production data per farms.	**Aggregation level**: required to establish a complete picture of the sample representativeness. Example: production at farm, local (Monastir) or national level.
Temporal replication: required to obtain a more detailed and reliable picture and to obtain consistent results. Example: production data per year.	**Format**: is important to define the format of the data needed. Example: shapefiles, geographic coordinates, text or documents.

The choice of spatial and temporal dimensions can influence the analysis results and the location of the AZA, and therefore, the decision making. In this study, the area analysed corresponds to the governorate of Monastir, more concretely, the coastal zone including land and sea. This study area is relatively small and the information collected have to be very precise, specific and clear.

Introducing sea cages in the ecosystem may alter the dynamic and can produce potential negative impacts. Aquaculture development is linked with the environment and it is essential to take a short, medium and long point of view of how this activity can influence on the ecosystem and how the ecosystem can influence this activity.

Regarding socioeconomic aspects, it is important to delimit the time scale for decision making. Administrative and legal components may help selecting this time scale: having a scale prediction of the production and benefits can help in investment process. In this study, the process of gaining social acceptability will vary in time: how the artisanal fisheries is evolving with aquaculture sector (size of group affected, how long?, where?).

2.2. Spatial modelling framework, GIS and general procedures

After data and information collection and database creation, the shapefiles have been organized and modified. This process has been realized with QGIS 2.18.12 (QGIS Development Team, 2017), a free and open source GIS.

The datum used in this study was the World Geodetic System 1984 (WGS84) and a projected coordinate reference system called Universal Transverse Mercator (UTM) in zone 32 N (European Petroleum Survey Group or EPSG: 32632).

The overall process to determine the AZA in Monastir, is hereunder explained (modified from Silva *et al*. 2011):

- <u>First stage</u>: Basic data of Monastir and aquaculture location were used to create the base map of the study. Administrative constraints and land use which may cause conflicts among users, have been used as an exclusion criteria. The map of uses and the base map were analysed and some area of interest for aquaculture were determined (Figure 10). In this stage, all farms location was studied, valuated and finally categorized.

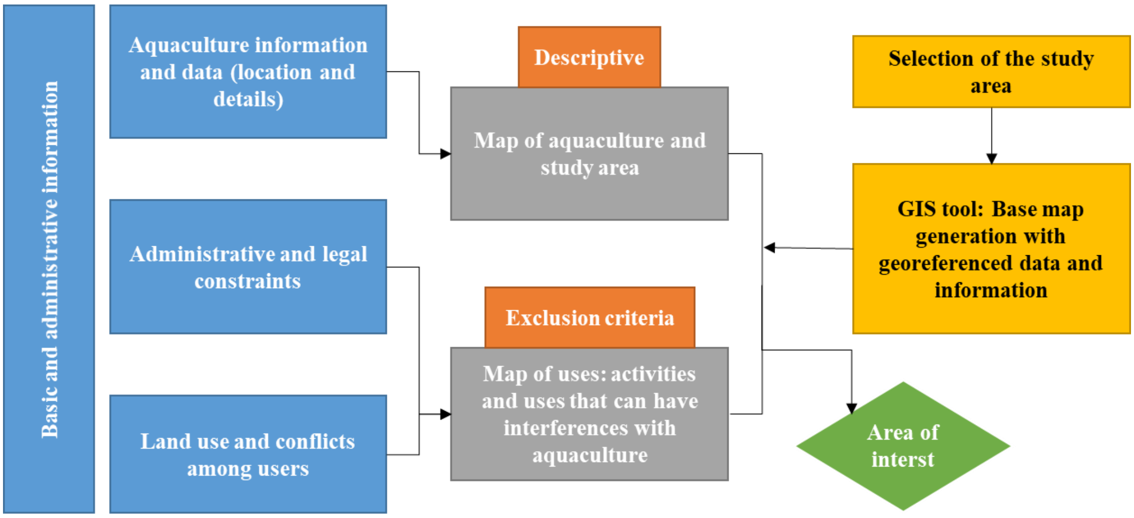

Figure 10: First stage of the spatial analysis. Thematic maps creation (grey rectangle) from basic and administrative information (blue rectangle) with GIS (yellow and orange rectangles). Delimitation of areas of interest for aquaculture (green rectangle). Modified from Silva et al. (2011).

- Second stage: The environmental monitoring programme per farms were requested. However, only two farms have sent this information, which have been included in the study as tables. Parameters of water quality were included as descriptive maps. The production carrying capacity have been calculated and introduced in the base map. Different maps of compatibility were done using factors and index outlined in the next section (Figure 11). In this stage, the AZA was delineated and the zones of interest categorized by compatibility degrees.

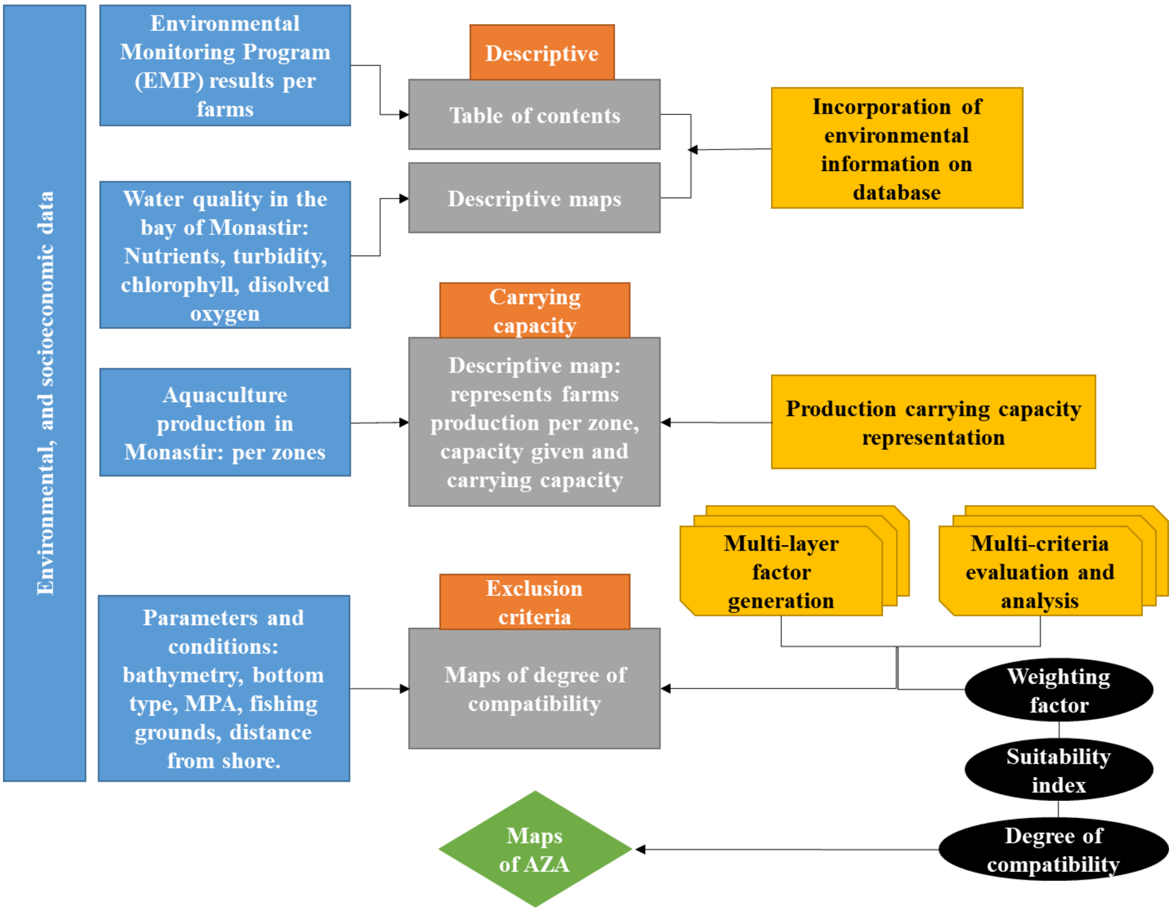

Figure 11: Second stage of the spatial analysis. Thematic maps creation (grey rectangle) from environmental and socioeconomic information (blue rectangle) with GIS (yellow and orange rectangles). Delimitation of AZA (green rectangle) and factors used (black circles). Modified from Silva et al. (2011).

It is important to know that all parameters which interact in the area can have negative impacts with aquaculture facilities, can define an area as incompatible. This kind of area should be excluded from the analysis based on the exclusion criteria. The exclusion criteria remove concrete zones from the area of study. An example of exclusion criteria is the existence of *Posidonia oceanica* meadow or other sensitive ecosystems in the area.

2.3. Degree of compatibility

2.3.1. Degree of compatibility estimation

Having integrated all the information obtained and having realised base and descriptive maps, suitable index and weighting factors have been estimated. Some parameters have been classified following the criteria explained in a study carried out in the coast of Andalucía (Del Castillo y Rey and Macías, 2006). The degree of compatibility has been calculated according to the following formula:

$$DC = 100 \times \frac{\sum_i^n K_i \times SI_i}{\sum_i^n K_i}$$

Where: DC = Degree of compatibility.

K_i = Weighting factor applied to each parameter considered.

SI_i = Suitability index applied in the bay according to the potential influence of each parameter.

i = Parameter.

n = Number of parameters.

The degree of compatibility will vary from -10000 to 100 and according to the study carried out by Del Castillo y Rey and Macías (2006), the following ranking was established (Table 6):

Table 6. Final assessment according to the degree of compatibility calculated. DC: Degree of Compatibility.

Value	Final assessment
-10000 < DC < -30	Discordant zone
-30 ≤ DC ≤ 30	Moderately suitable zone (Moderately compatible zone)
30 < DC < 100	Suitable zone (Compatible zone)

Discordant zones are considered less suitable and should be further investigate and analysed due to the absence of reliable and comparable data.

2.3.1.1. Weighting factor ($\boldsymbol{K_i}$)

K_i can take values from 1 to 10, in line with the importance of each parameter and its influence with the aquaculture sector. Different values have been assigned for each parameter considered in the study. This factor will fluctuate according to the importance of the parameter for the sustainable aquaculture development in the bay. Besides, the value will depend on data and information reliability. The higher the value, the greater is the parameter importance and reliability.

2.3.1.2. Suitability index ($\boldsymbol{SI_i}$)

The parameters concerned in this study have been classified by ranges or categories (at least two), in which the values assigned will vary according to:

- -100: This value represents an area considered as exclusionary due to the negative impact of sea cages on the environment (*Posidonia* meadows) or of the environment on the sea cages (harmful algal blooms, polluted sites, waste water discharges). Also, the incompatibility between different maritime activities and other administrative uses (fishing grounds, maritime routes, marine protected areas and military areas) are considered as exclusionary areas. The exclusion criteria will be applied in these cases.

- -1: Unsuitable zone for an adequate aquaculture development. However, these zones include features allowing limited farming conditions, but it remains a very unwise area to implement aquaculture.

- 0: Moderately suitable area. The use of these zones is recommendable if there were measures to reduce constraints and could be managed.

- 1: Suitable zone. These ranges present all the optimum characteristics for a sustainable aquaculture development.

2.3.2. Scenarios

Two scenarios have been considered:

1) The first one takes into account only three ranges of compatibility: suitable zone, moderately suitable area and discordant zone. The criteria selected to analyse the area were:
   a) Bathymetry: 25-50 m as suitable.
   b) Bottom type: *Posidonia* meadow as an excluded area (and 800 m buffer)
   c) Aquaculture facilities: licensing areas as excluded area
   d) Fishing grounds: as excluded area
   e) Water discharge and tourist area: as excluded area
   f) Distance from shore: more than 6 nautical miles as moderately suitable area.

This scenario have not taken into account weighting factors and therefore, only three resulting categories have been mapped.

2) The second one takes into account the ranges and conditions of the tables 7 to 14 (summarized on the table 15).

Only the results with a degree of compatibility from 30 to 100 have been mapped. Unlike the first scenario, this one have taken into account ranges from 0 to 10 nautical miles as a suitable area (SI: 1) and for more than 10 as moderately suitable area (SI: 0).

2.3.3. Parameters considered (scenario 2)

2.3.3.1. Bathymetry

The suitable depth range to locate aquaculture facilities ranges from 25 to 50 meters (Table 7). These depths can aid in mitigating the potentials impacts related with sea cages, such as waste accumulation on the sea bed, and can prevent financial losses associated with nets damages.

Within a range from 20 to 25 meters, the location of the farms is considered less suitable due to the size of the net. As a rule of thumb, the cage net depth should not be deeper than one third or half (at most) of the site's depth (FAO, 2015).

The range under 20 meters is unsuitable from a technical, economic and environmental point of view. It is recommended that at least 15 meters should be left between the net base and the sea bed (FAO, 2015).

In this study area, locating sea cages up to 50 meters is not considered due to financial and logistical problems.

Table 7. Determination of the bathymetry suitability index (SI_{bathy}) and its weighting factor (K_{bathy})

Parameter		Value	K_{bathy}
Bathymetry	< 20 m	SI_{bathy} = -1	7
	20 - 25 m	SI_{bathy} = 0	
	25 - 50 m	SI_{bathy} = 1	
	> 50 m	SI_{bathy} = 0	

2.3.3.2. Bottom type

Sandy and muddy bottoms are suitable bottom types to locate sea cages, providing good anchorage. Mixed substrates are considered less suitable (FAO, 2015).

Posidonia oceanica meadow is a strictly discriminant area. This type of sea bed and other phanerogams meadows are classified as particularly sensitive area and they are susceptible to degradation processes (Table 8). Sea cages should be located taking into account the current's prevailing direction and taking into account a buffer zone of 800 m around the meadow (IUCN, 2009).

Table 8. Determination of the bottom type suitability index (SI_{bt}) and its weighting factor (K_{bt})

Parameter		Value	K_{bt}
Bottom type	*Posidonia oceanica* meadow (< 800 m)	SI_{bt} = -100	6
	Sandy and muddy bottoms	SI_{bt} = 1	
	Mixed substrates	SI_{bt} = 0	

2.3.3.3. Marine Protected Area

As regards the special protection areas, such as Marine Protected Areas, the suitability index is strictly discriminant. In this study area, it has been considered the incompatible with aquaculture activities. However, the area of influence is defined as medium area of interest (Table 9). The MPA defined in the study was defined by a MedMPAnet project and is not yet established (CAR/ASP, 2015).

Table 9. Determination of the Marine Protected Area suitability index (SI_{MPA}) and its weighting factor (K_{MPA})

Parameter		Value	K_{MPA}
Marine Protected Areas	MPA area	SI_{MPA}= -100	7
	Area of influence	SI_{MPA}= 0	
	Outside MPA	SI_{MPA}= 1	

2.3.3.4. Aquaculture facilities

To prevent transmission of pathogens and diseases between farms, a minimum distance between the different facilities is needed. Many parameters have to be considered, such as nutrient discharge, current speed and depth. In this study area, it has been estimated a minimum distance of 500 meters between farms as suitable (Table10). Moreover, another granting area is a discriminant zone and a buffer zone less than 500 meters is a medium area of interest (Karakassis *et. al*, 2013).

Table 10. Determination of the aquaculture facilities suitability index (SI_{Aq}) and its weighting factor (K_{Aq})

Parameter		Value	K_{Aq}
Aquaculture facilities	Granting area	SI_{Aq}= -100	6
	< 500	SI_{Aq}= 1	
	> 500	SI_{Aq}= 0	

2.3.3.5. Fishing areas

Artisanal fishing grounds is an exclusive use area, and to avoid conflicts among users, it is considered an unsuitable zone to locate sea cages.

Due to the low level of data reliability, two rankings have been considered in this study to establish artisanal fishing grounds suitability index (Table 11):

1. Valuation for existing farms (SI_{fish}= -1): to determine the current situation of the farms, fishing grounds have been considered as unsuitable areas. However, these areas may have a special agreement between the fishermen and aquaculture producers: due to the FADs generated around the facilities, fishermen should fish within the concession area.

2. Valuation for the rest of the study area (SI_{fish}= -100): to determine the situation in the bay of Monastir and to establish if there are suitable zones to the sustainable aquaculture development, fishing grounds have been considered as an exclusion parameter. This was decided taking into account the conflicts that may occur if a new aquaculture facility could be installed in artisanal fishing grounds.

Table 11. Determination of the fishing areas suitability index (SI_{fish}) and its weighting factor (K_{fish})

Parameter		Value	K_{fish}
Fishing areas	Artisanal fishing grounds	SI_{fish}= -100 SI_{fish}= -1	5
	No artisanal fishing grounds	SI_{fish}= 1	

2.3.3.6. Waste water discharges

To understand how waste water discharges may affect aquaculture facilities, both from an environmental and sanitary points of view, a complete dispersal study should be undertaken. This parameter may trigger long-term adverse economic impacts to the aquaculture company.

Given the absence of detailed data on currents and velocity, it has been considered to apply an approximate 2 km buffer zone (Table 12). Usually, the shape of the buffer should correspond with the currents direction detected near discharge point.

Table 12: Determination of the waste water discharge suitability index (SI_{ww}) and its weighting factor (K_{ww})

Parameter		**Value**	**K_{ww}**
Waste water discharges	Spreading of contaminants affect farms (< 2 km)	SI_{ww}= -100	5
	More than 2 km from the discharge point	SI_{ww}= 1	

2.3.3.7. Tourist areas

Areas of tourist interest is part of the administrative matter analysed in this study. Aquaculture may negatively interfere with the tourist sector, due to its potential negative visual impact. In this study, a geographical information database has been created, in which, tourist beaches and hotels zones have been considered as tourist areas along the coast. Besides, 4 km from the coast have been estimated as a potential negative visual impact, becoming an unsuitable zone for aquaculture (Table 13).

Table 13. Determination of the tourist areas suitability index (SI_{tour}) and its weighting factor (K_{tour})

Parameter		**Value**	**K_{tour}**
Tourist areas	< 4 km	SI_{tour}= -1	4
	> 4 km	SI_{tour}= 1	

2.3.3.8. Distance from the home port

The distance between the sea cages and the home port is an essential component to take into account. It is important to consider this element due to its economic and financial impact on aquaculture facilities. In this study, 10 nautical miles have been considered as the maximum suitable distance to establish an aquaculture facility (Table 14). More than 10 nautical miles could involve financial losses related with fuel costs.

Table 14. Determination of the home port distance suitability index (SI_{port}) and its weighting factor (K_{port})

Parameter		Value	K_{tour}
Home port distance	< 10 nm	SI_{tour}= 1	5
	> 10 nm	SI_{tour}= -1	

Table 15. Overview of all the parameters and uses of the area, considered to calculate the degree of compatibility. Each parameters are ranked according to ranges or conditions and its suitable index (SI) and weighting factor (K).

Parameters and uses	Level of interest		Weighting factor K
	Ranges and conditions	**SI**	
Bathymetry	< 20 m	-1	7
	20 - 25 m	0	
	25 - 50 m	1	
	> 50 m	0	
Bottom type	*Posidonia oceanica* meadow (800 m)	-100	6
	Sandy and muddy bottoms	1	
	Mixed substrates	0	
Marine Protected Areas	MPA area	-100	7
	Area of influence	0	
	Outside MPA	1	
Aquaculture facilities	Granting area	-100	6
	< 500 m	1	
	> 500 m	0	
Fishing areas	Artisanal fishing grounds	-100	5
	Outside fishing grounds	1	
Waste water discharges	Spreading of contaminants affect farms (< 2 km)	-100	5
	More than 2 km from the discharge point	1	
Tourist areas	< 4 km	-1	4
	> 4 km	1	
Home port distance	< 10 nautical miles	1	5
	> 10 nautical miles	0	

2.4. Production carrying capacity

2.4.1. Definition and carrying capacity categories

There are a large number of definitions made by different authors. Ross *et al.*, 2013, defined carrying capacity as follows:

"Carrying capacity is an important concept for ecosystem-based management, which helps set the upper limits of aquaculture production given the environmental limits and social acceptability of aquaculture, thus avoiding "unacceptable change" to both the natural ecosystem and the social functions and structures."

Carrying capacity for aquaculture is based primarily on four different types or categories:

- Physical carrying capacity: takes into account the physical factors of the waterbody and the faming system, to identify the total area suitable for aquaculture.
- Production carrying capacity: estimates the maximum aquaculture production.
- Ecological carrying capacity: is the magnitude of aquaculture production that can be supported without leading to significant changes to ecological processes, species or communities in the environment.
- Social carrying capacity: is the amount of aquaculture that can be developed without adverse social impacts.

2.4.2. Production carrying capacity estimation

Data and information collected were not enough to calculate the carrying capacities, which requires significant amount of specific data.

However, it has been possible to calculate the production carrying capacity per farm, following the criteria of the Greek legislation, explained in the study carried out by Karakassis *et. al*, 2013. The production carrying capacity have been calculated according these concepts and formula:

$$PCC = [150 + 80(E - 1)] \times f_a \times f_b \times f_k$$

Where: PCC = production carrying capacity (t/ha)

E = Area of the farm concession (in hectares)

f_a = Distance coefficient

f_b = Depth coefficient

f_k = Openness/exposure of the area or currents

Integers = 150 t/ha is the starting value for the first hectare. 80 tonnes for each additional hectare.

2.4.2.1. Distance coefficient: $\boldsymbol{f_a}$

Following the Greek legislation criteria, each farm of Monastir have been characterized with a distance coefficient f_a = 2, due to the fact that all sea cages are located beyond 1000 meters from the shore (Table 16).

Table 16. Fish farm distance from the shore and its corresponding coefficients. f_a: distance coefficient, from 1 to 2.

Farm distance from the coast	**< 100 m**	**101–400 m**	**401–1000 m**	**> 1001 m**
$\boldsymbol{f_a}$	1	1.25	1.5	2

2.4.2.2. Depth coefficient: $\boldsymbol{f_b}$

In Monastir, farm facilities are located at depths between 19 m and 40 m, which correspond to a depth coefficient f_b = 0.9 to 1.5 (Table 17).

Table 17. Depth under the fish farm and its corresponding coefficients. f_b: depth coefficient, from 0.9 to 2.

Depth under the fish farm	< 20m	21–35 m	36–50m	> 51 m
$\boldsymbol{f_b}$	0.9	1	1.5	2

2.4.2.3. Exposure of the area or currents: $\boldsymbol{f_k}$

In this study, the openness of the bay or exposure of the fish farms to currents has been considered as open, with a f_k = 1.5 (Table 18).

Table 18. Exposure of the area and its corresponding coefficients. f_k: openness coefficient, from 1 to 2.5.

Openness/exposure of the fish farm location	Closed	Open	Very exposed	Flow speed
$\boldsymbol{f_k}$	1	1.5	2	2.5

2.4.2.4. Coefficients assigned to each farm

The following table summarises the coefficients assigned to each farm and corresponding area. It is important to highlight that FA_10 is not included in the estimation of the production carrying capacity, because its activity is stopped since 2012.

Table 19: Overview of coefficients considered to calculate production carrying capacities. $\boldsymbol{f_a}$: Distance coefficient. $\boldsymbol{f_b}$: depth coefficient. $\boldsymbol{f_k}$: Exposure of the area. E: area (hectares).

Farms	f_a	f_b	f_k	E
FA_1	2	0.9	1.5	45
FA_2	2	0.9	1.5	36
FA_8	2	1	1.5	80
FA_3	2	1	1.5	32
FA_4	2	1.5	1.5	69
FA_6	2	1	1.5	45
FA_9	2	1	1.5	45
FA_5	2	1	1.5	30
FA_7	2	1	1.5	45
FA_11	2	1.5	1.5	45
FA_12	2	1	1.5	24
FA_13	2	1	1.5	36
FA_10	2	1	1.5	-

3. RESULTS

3.1. Land uses and coastal activities: thematic cartography

Northwest sector: from STEG to the airport

This area (Figure 12) ranges from the Société Tunissienne de l´Électricité et de Gaz (STEG) (industrial zone) to the airport of Monastir. Regarding the administrative uses, this zone covers most of the tourist areas in Monastir: hotels and tourist beaches. Besides, there are salt mines and a river. A waste water discharge point is located in the river mouth. These discharges are mainly derived from urban and industrial activities. Concerning the maritime space, there is an artisanal fishing ground located on the upper right part of the figure.

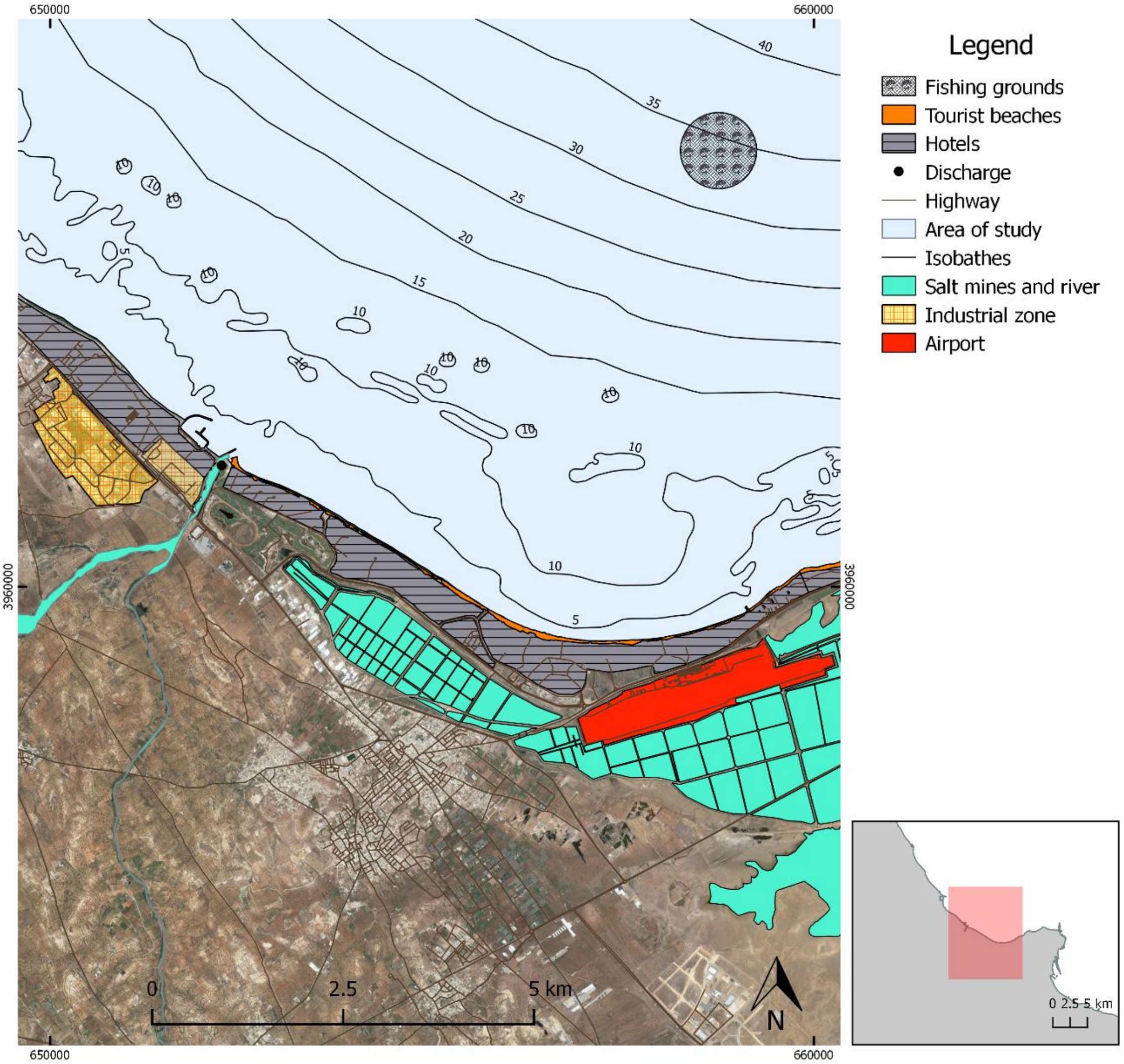

Figure 12. Northwest sector: from STEG to the airport. Land use and coastal activities: Tourist areas (hotel and tourist beaches), industrial zones (STEG), airport, discharge point and artisanal fishing grounds.

North sector: from leisure port to fishing port

This area (Figure 13) ranges from the leisure port to the fishing port of Monastir (aquaculture home port). The landscape of this region is characterised by its tourist areas, (hotels, tourist beaches and leisure port), its cultivation areas, its fishing port and landing areas. Regarding the maritime space, this is where the *Posidonia oceanica* meadow begins. Besides, there are artisanal fishing grounds and aquaculture facilities: FA_1, FA_2 and FA_3, which are located near the coast and above the meadow.

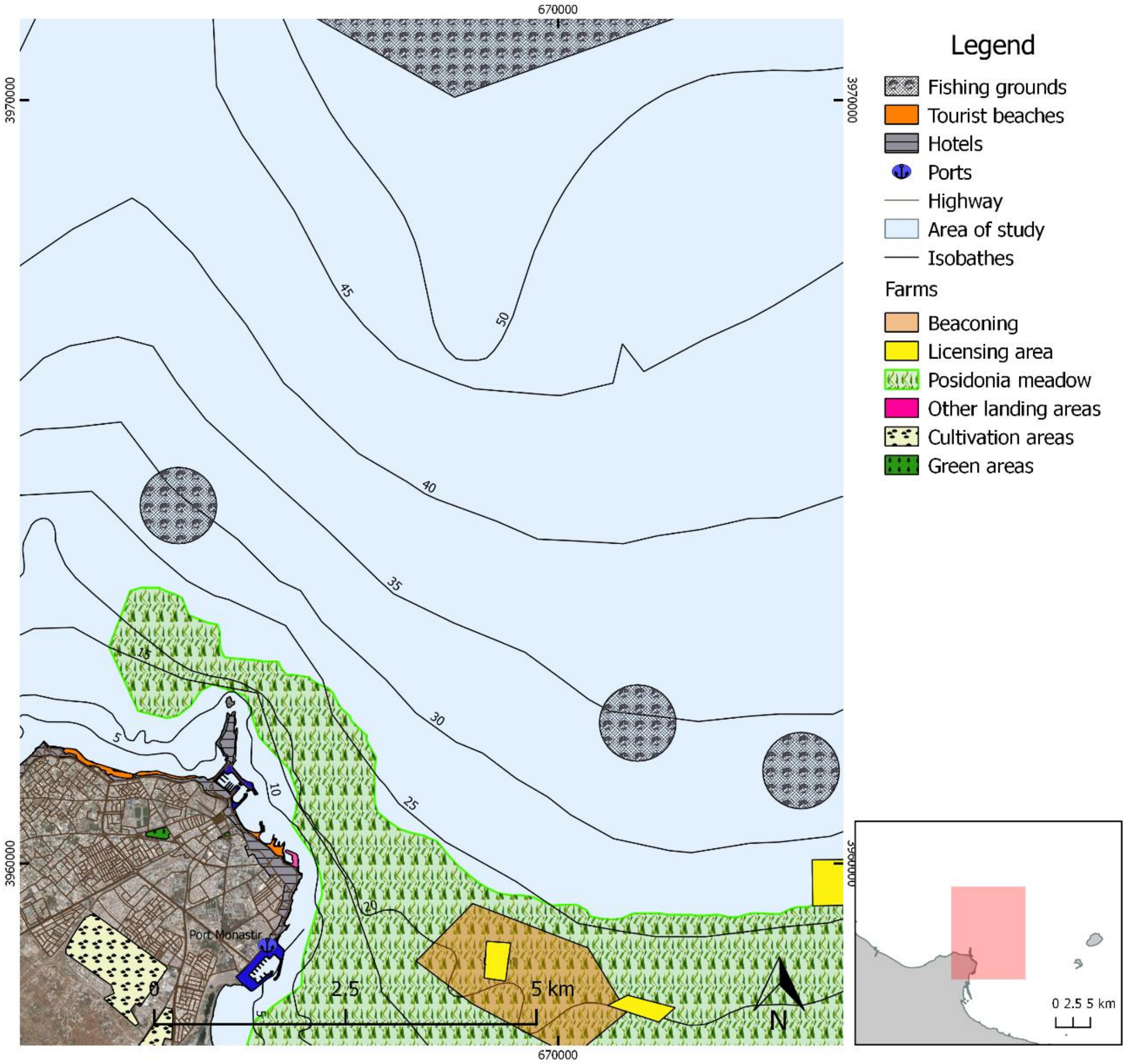

Figure 13. North sector: from leisure port to fishing port. Land use and coastal activities: Tourist areas (hotel and tourist beaches), cultivation area, aquaculture facilities and artisanal fishing grounds.

Central sector: from Frina to Sayada

This area (Figure 14) ranges from Frina town (south of the industrial zone) to the fishing port of Sayada. There are thirteen waste water discharge points (mouth of Khniss River, salt mines, Ksibet Mediouni urban zone and port, Lamta and Sayada urban zones. The maritime space is characterised by the Posidonia meadow, two fishing ports (and its maritime routes) and other landing areas (such as Khniss). Regarding aquaculture activity, an assembly area (sea cages) located on the upper left side of the figure.

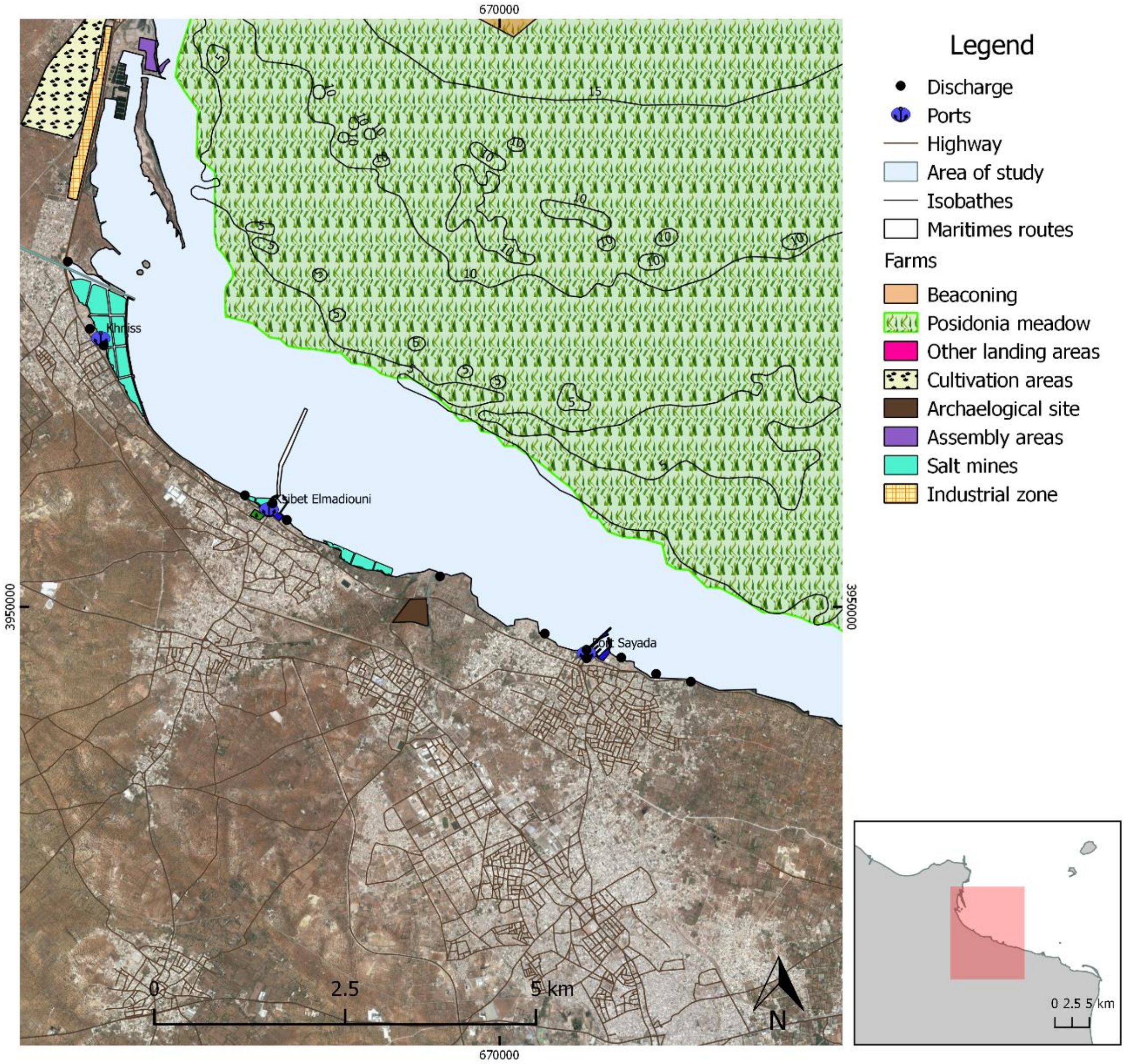

Figure 14. Central sector: from Frina to Sayada. Land use and coastal activities: cultivation area, industrial zone, salt mines, archaeological site, and fishing ports.

<u>Central sector: Téboulba</u>

This area (Figure 15) ranges from Téboulba to Bekalta. The fishing port of Téboulba is also an aquaculture home port and some assembly areas (sea cages) where detected around the port. There are a defined maritime route and other landing areas along the coastline. Concerning the maritime space, *Posidonia* meadow is divided in two parts due to shallow depth. Besides, an aquaculture licensing area and beaconing (FA_9) are located on the right side and a part of the MPA buffer zone on the upper part of the figure.

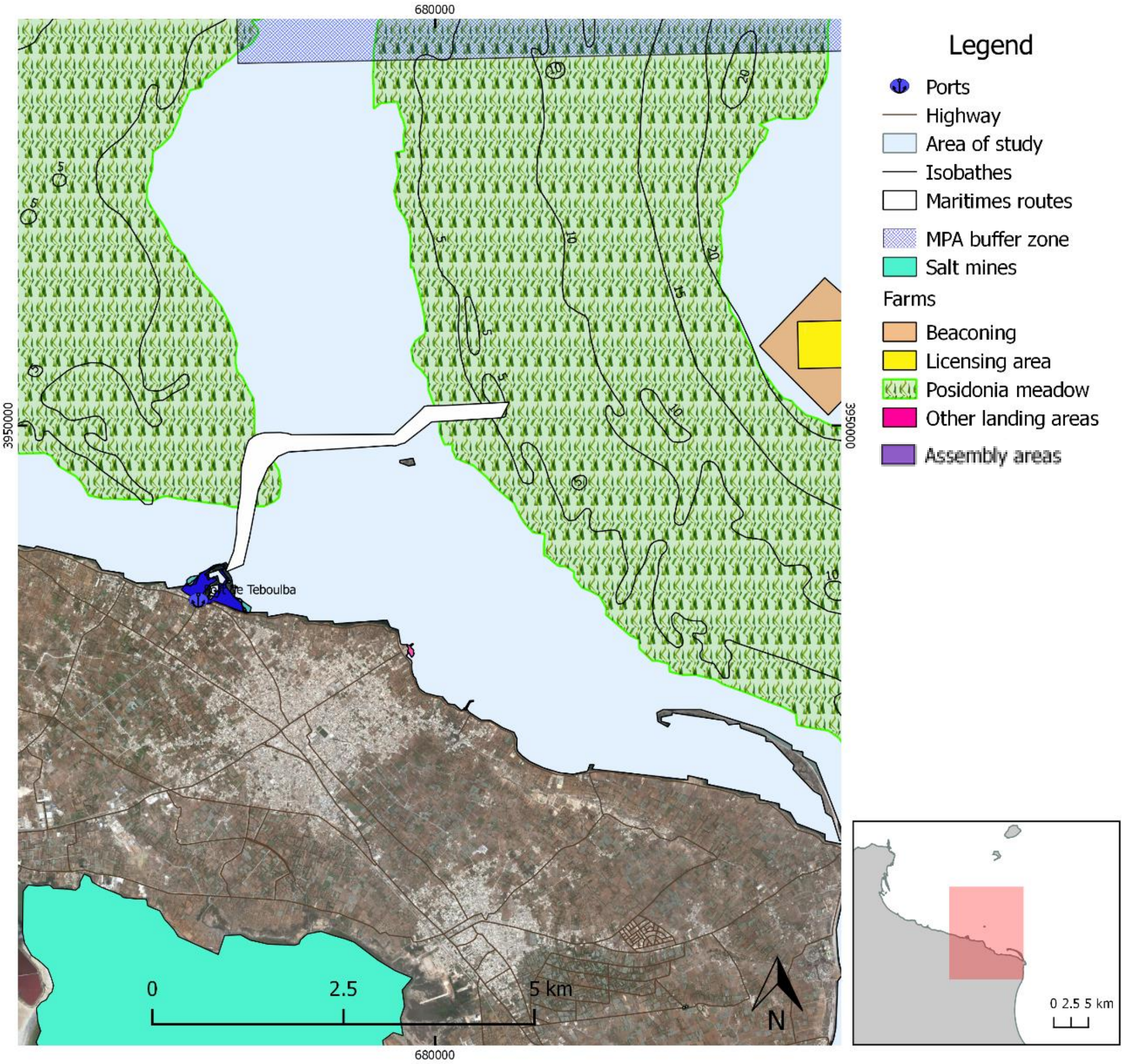

Figure 15. Central sector: Téboulba. Land use and coastal activities: salt mines, fishing port, assembly areas, maritime routes, beaconing and licensing farm area, MPA buffer zone.

South sector: Békalta

This area (Figure 16) is characterised by its fishing port activities. The port of Békalta is one of the aquaculture home ports in the bay of Monastir. Regarding the maritime space, there is an artisanal fishing ground, aquaculture beaconing and licensing areas and this is where the *Posidonia* meadow ends.

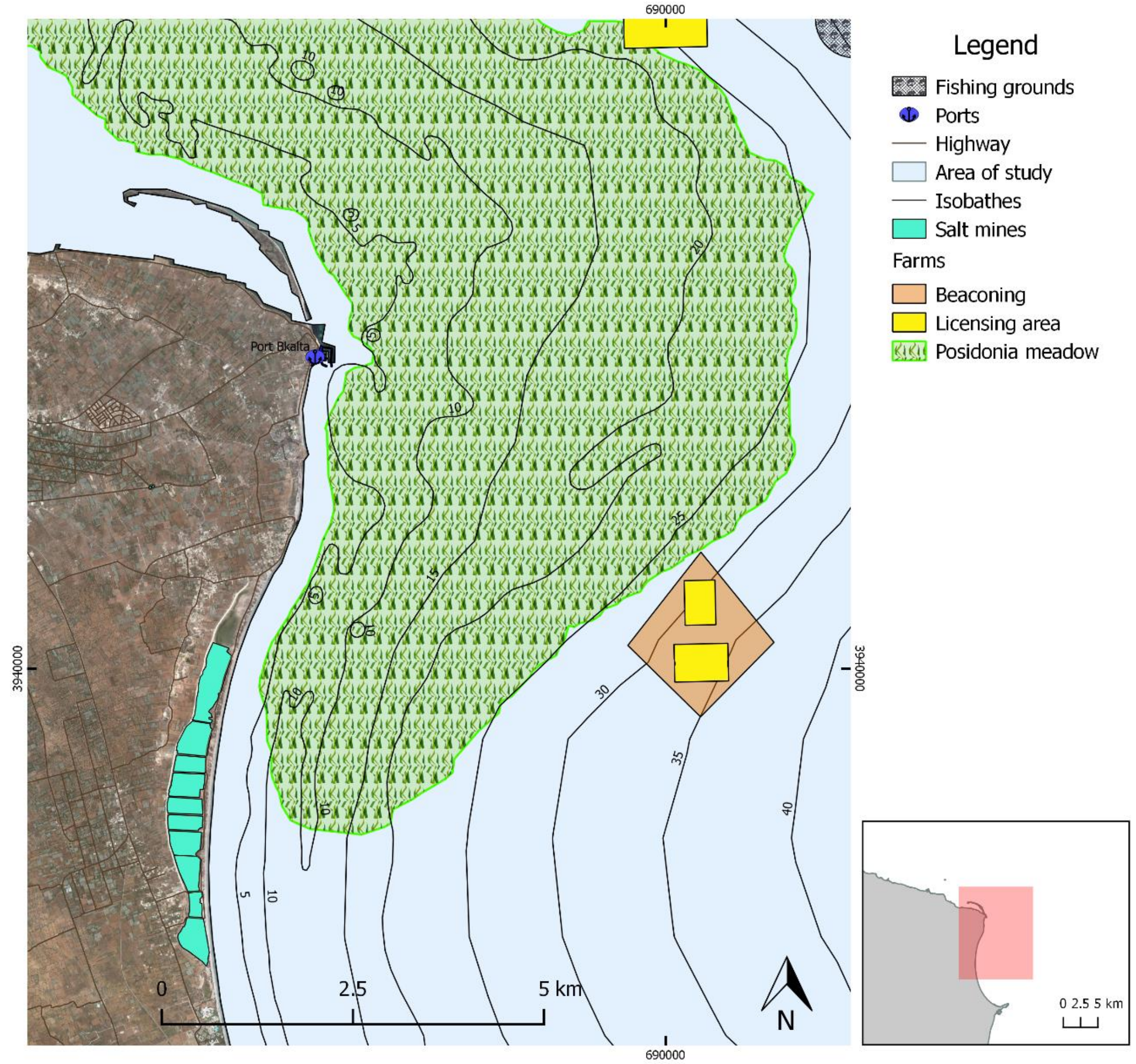

Figure 16. South sector: Békalta. Land use and coastal activities: salt mines, fishing port, beaconing and licensing farm area and artisanal fishing grounds.

Overall components of the coastal zone

The Figure 17 regroups all the components mentioned above: land and maritime uses and related activities.

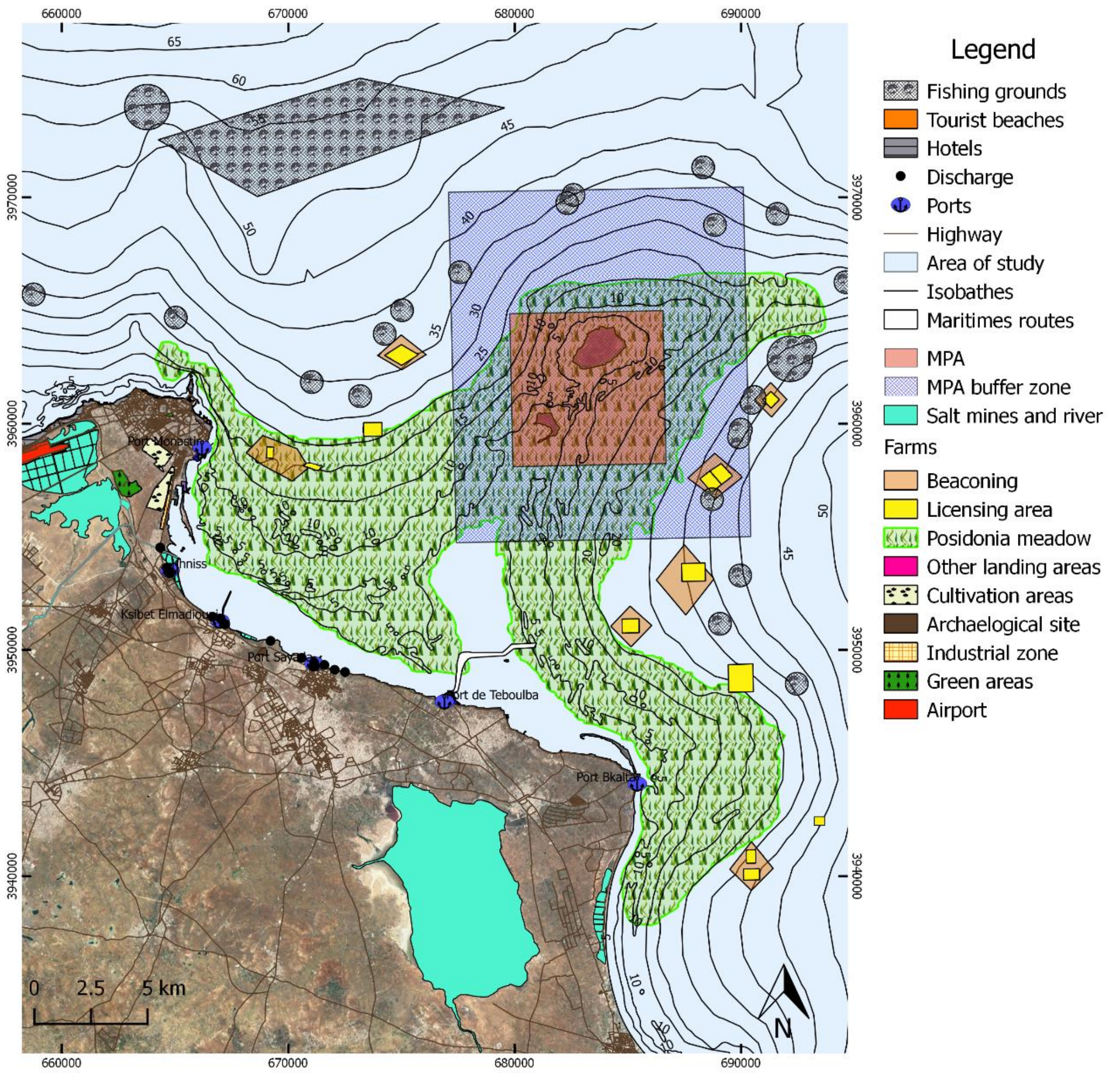

Figure 17. Land use and coastal activities in the bay of Monastir.

3.2. Water quality

3.2.1. Environmental monitoring programme (EMP)

Aquaculture development can create potential negative impacts, which threaten the durability of this activity. An EMP is therefore indispensable to assess the environmental quality of the site.

Each aquaculture facilities assess the environmental quality of their site annually. Given the data confidentiality, the area where the EMP was done and the name of the farm, may not be disclosed in this study.

The table 20 shows the average, maximum and minimum results of 7 monitoring stations, obtained in 2016. The sampling was realized on surface and in the depth for each parameter, except for temperature and oxygen. The results of these last parameters are the average values for each depth. Generally, EMP results are in compliance with the Tunisian regulations. Only the suspended matter exceeds the limit of 30 mg/l (50.3 mg/l in surface and 57.3 mg/l in deep). The EMP results were compared with the Environmental Quality Standards for Mediterranean marine finfish farming based on the response of the experts to a Delphi questionnaire (Karakassis and Sanchez-Jerez, 2012). The suspended matter also exceeds the critical limits of 7.5 mg/l in surface and 50 mg/l in deep (Annex 6). Nitrates also exceed the safe limit of 2 mg/l in deep with a value of 3.1 mg/l (maximum and minimum values of 3.22 mg/l and 2.87 mg/l, respectively) and do not surpass the critical value of 6 mg/l.

Table 20. Average values of the EMP, Tunisian standards and Delphi traffic lights. Red background: EMP results exceeding critical limits. Yellow background: EMP results between safe and critical limits. Green background: EMP results below the safe limit.

Parameters	unit	Results				Tunisian standards	Delphi traffic lights	
		Minimum	Maximum	Surface	Deep		Surface	Deep
PH	-	7.9	8.44	8.2	7.85	6.5-8.5		
Salinity	g/l	40.6	41.1	40.8	40.8	-		
Suspended matters	mg/l	49	62	50.3	57.3	30 mg/l		
Phosphor	mg/l	<0.1	<0.1	<0.1	<0.1	0.1 mg/l		
Nitrite	mg/l	<0.1	<0.1	<0.1	<0.1	5 mg/l		
Nitrate	mg/l	2.87	3.22	2.9	3.1	90 mg/l		
Temperature	ºC	-	-	19.9		-		
Dissolved oxygen	mg/l	-	-	13.62		-		

3.2.2. Environmental data of the bay of Monastir

Environmental data was obtained from APAL (Agence de protection et d'aménagement du littoral) sampling carried out in 2012. Due to the scarce or non-existent temporal replication of information, these results have been considered as descriptive and have not been included in the degree of compatibility assessment. Besides, this information has been represented in grids and defined in maps (Figure 18).

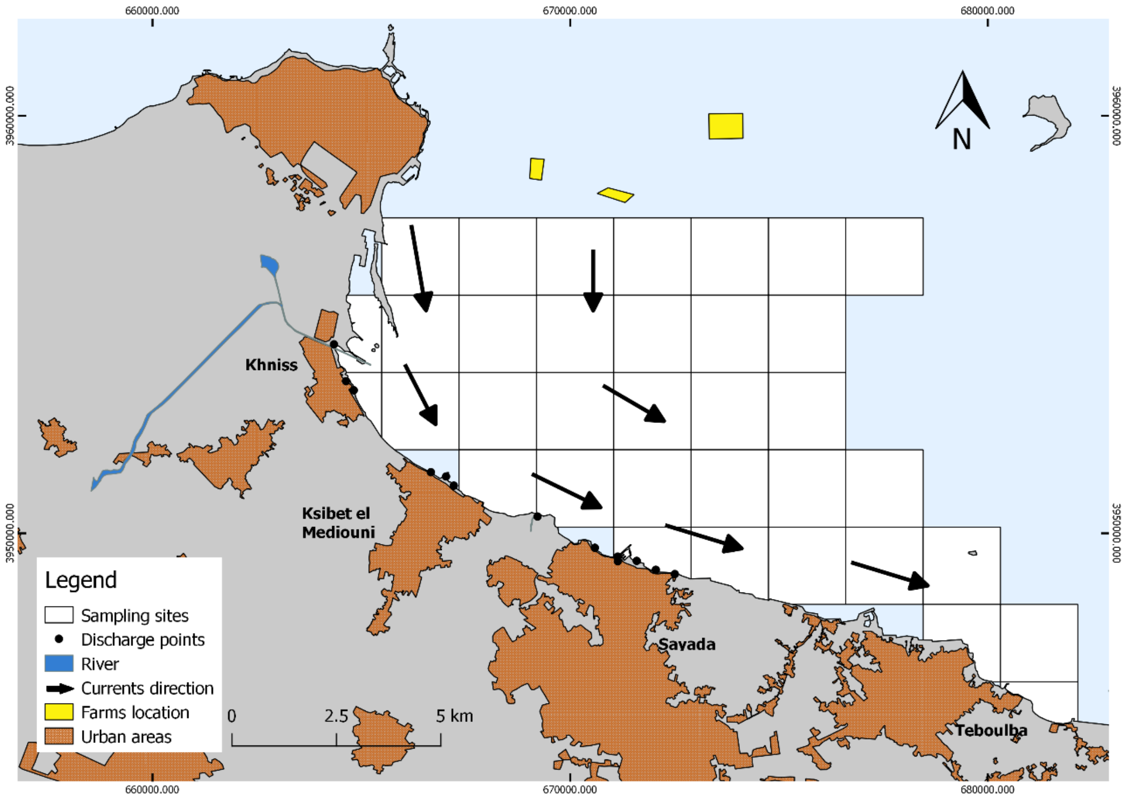

Figure 18. Grid corresponding to each sampling sites. Each grid cells (white cells) contains environmental values described in the previous section. Black arrows indicate the general direction of the currents in the bay of Monastir. Waste water discharge points are market with black dots and aquaculture facilities with yellow rectangle.

3.2.2.1. pH

The pH values vary from 8.46 to 8.81 (Figure 19). The highest values are located in the near-shore zone, more specifically in the mouth of the river (near Khniss) and near urban areas (Ksibet el Mediouni and Teboulba). On the top centre, the values increase to 8.64 in the area nearby two farms (FA_1 and FA_2).

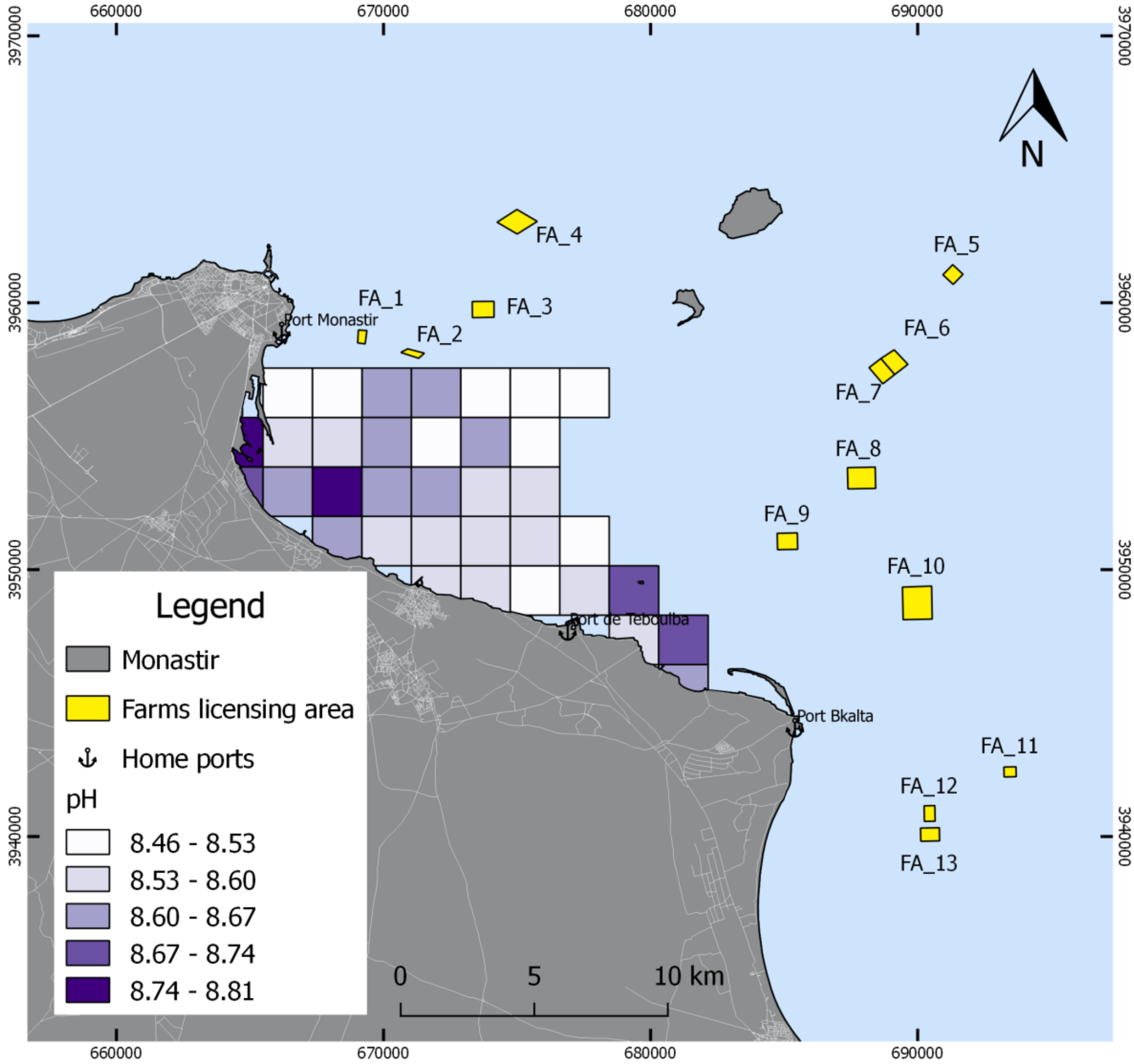

Figure 19: pH distribution map in the bay of Monastir.

3.2.2.2. Nitrates and nitrites

Nitrates and nitrites values range from 9 to 49 µg/l and 5 to 34 µg/l respectively (Figure 20). The distribution of these concentrations is very similar, and in particular nearby the aquaculture facilities located on the top centre. The highest concentrations are also located near the coastline: in the mouth river (near Khniss), Ksibet el Mediouni, Sayada and Teboulba areas.

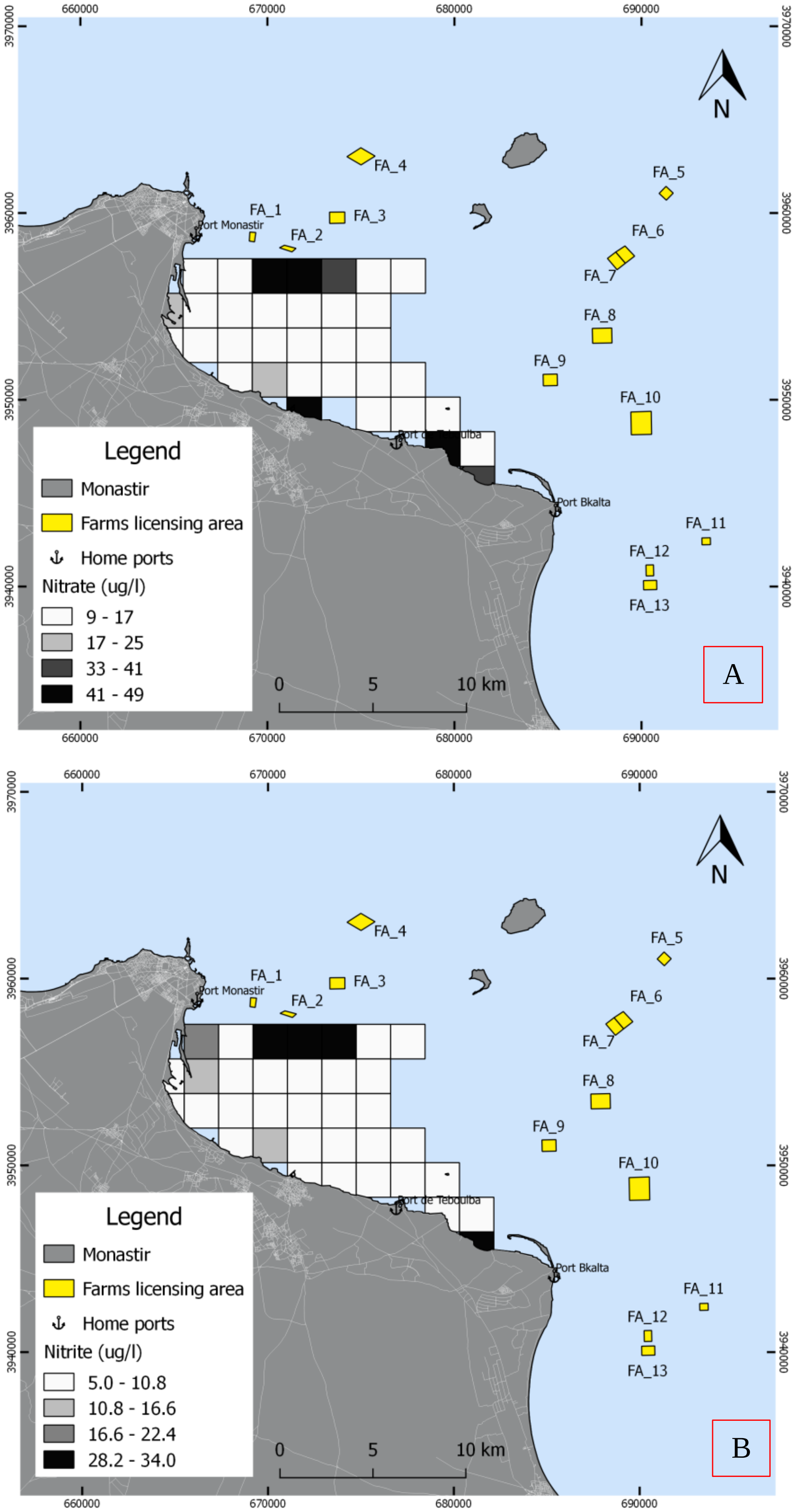

Figure 20. Nitrates (A) and nitrites (B) distribution map in the bay of Monastir, in µg/l.

3.2.2.3. Dissolved oxygen

Dissolved oxygen values vary from 6.08 to 10.8 mg/l (Figure 21). The oxygen distribution is fairly homogenous; however some high values appears near the coastline where there is an intense urban pressure: Khniss, Ksibet el Mediouni, Sayada and Teboulba.

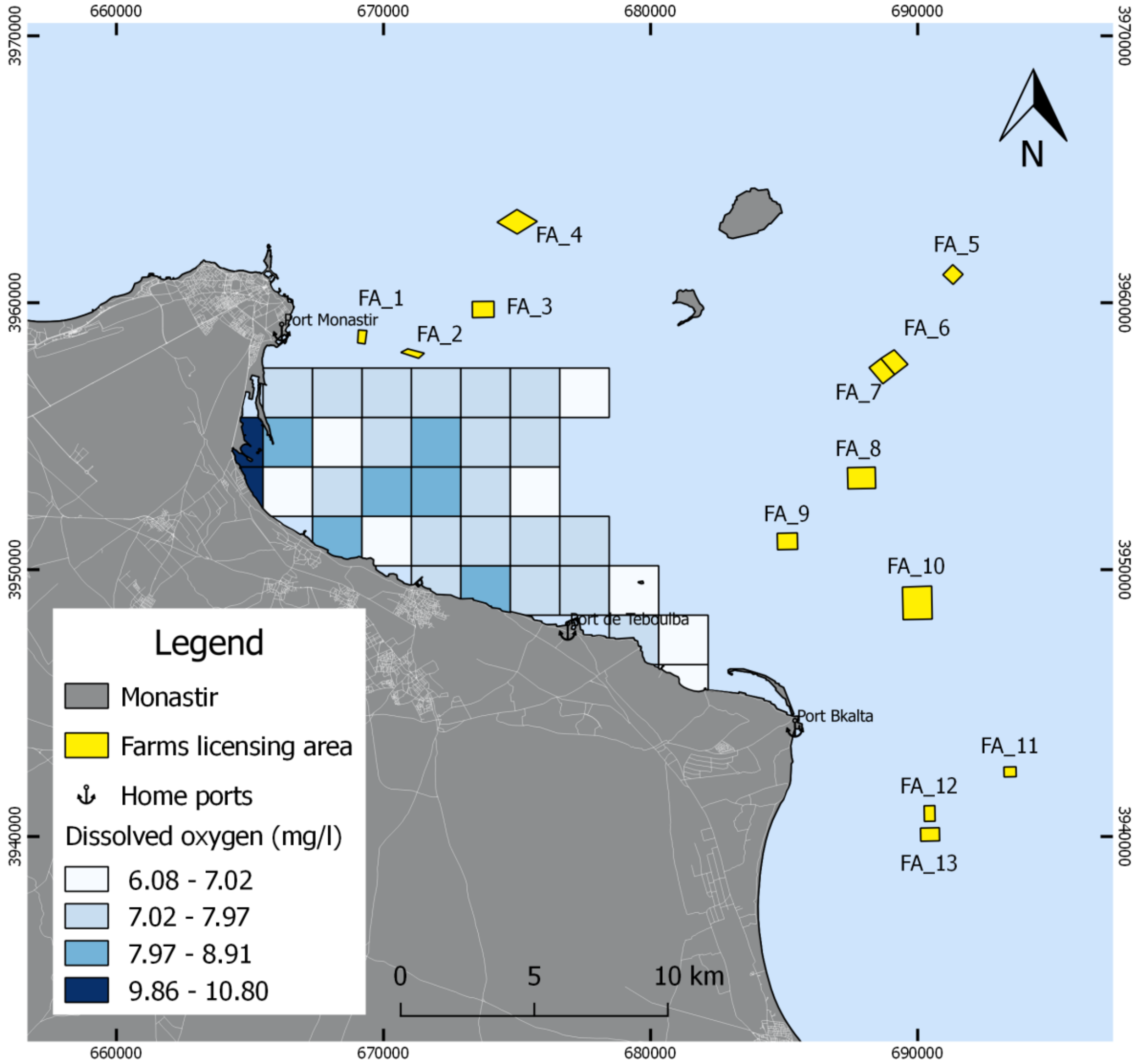

Figure 21: Dissolved oxygen distribution map in the bay of Monastir, in mg/l.

3.2.2.4. Phosphate

Phosphates values range from 6 to 1500 µg/l (Figure 22). The distribution of the highest concentrations is very similar to nitrates and nitrites distributions. Once again, the highest concentrations are located nearby the aquaculture facilities (on the top centre) and near the coastline: in the mouth river (near Khniss), Ksibet el Mediouni, Sayada and Teboulba areas.

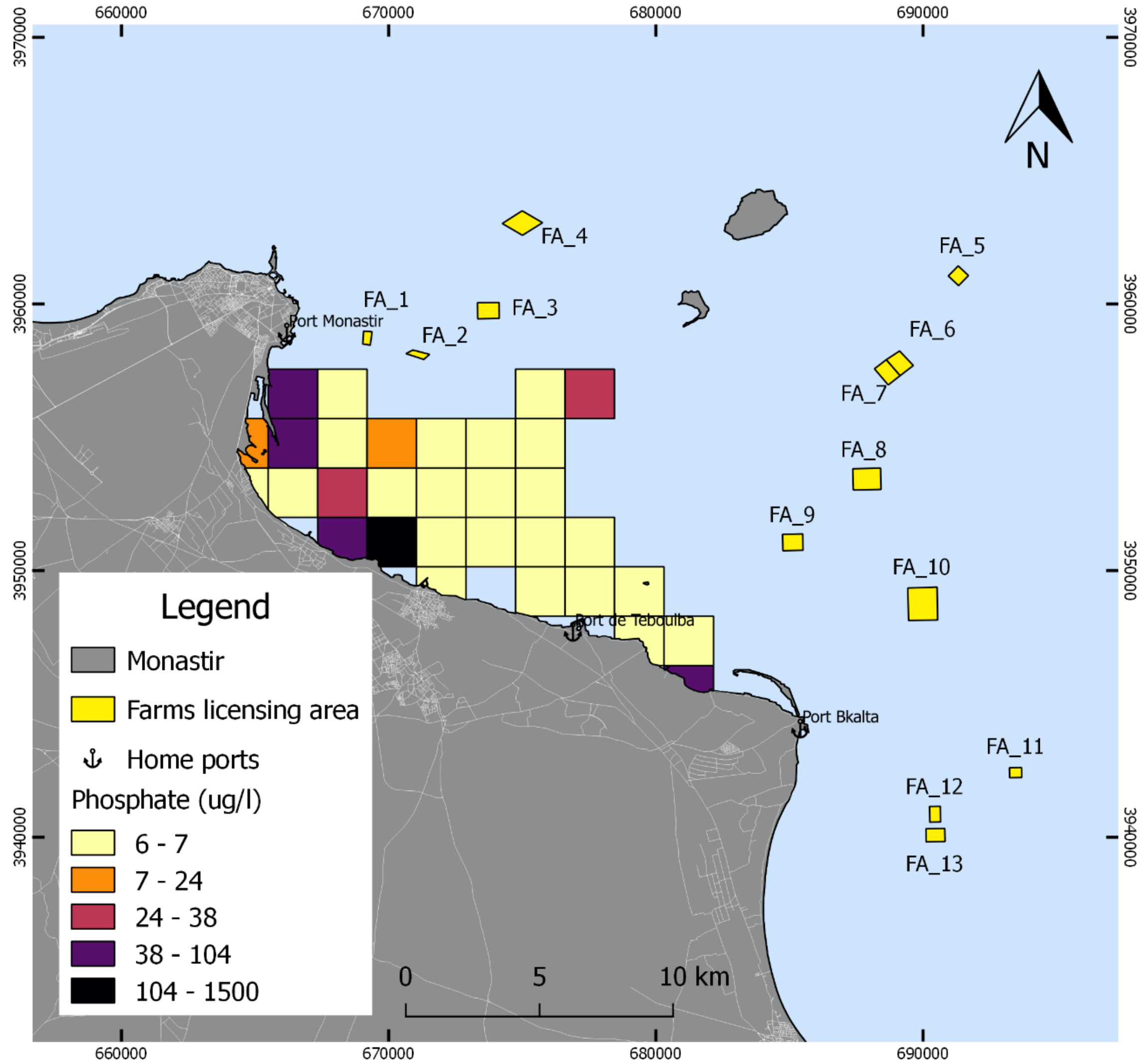

Figure 22: Phosphate distribution map in the bay of Monastir, in µg/l.

3.2.2.5. Suspended matter

Suspended matter values vary from 1 to 27.5 mg/l (Figure 23). The concentrations are high near the coastline (Khniss, Ksibet el Mediouni, Sayada and Teboulba) and decrease according to the distance from the coast. It should be noted that top centre values (nearby aquaculture facilities) do not appear in the data collected.

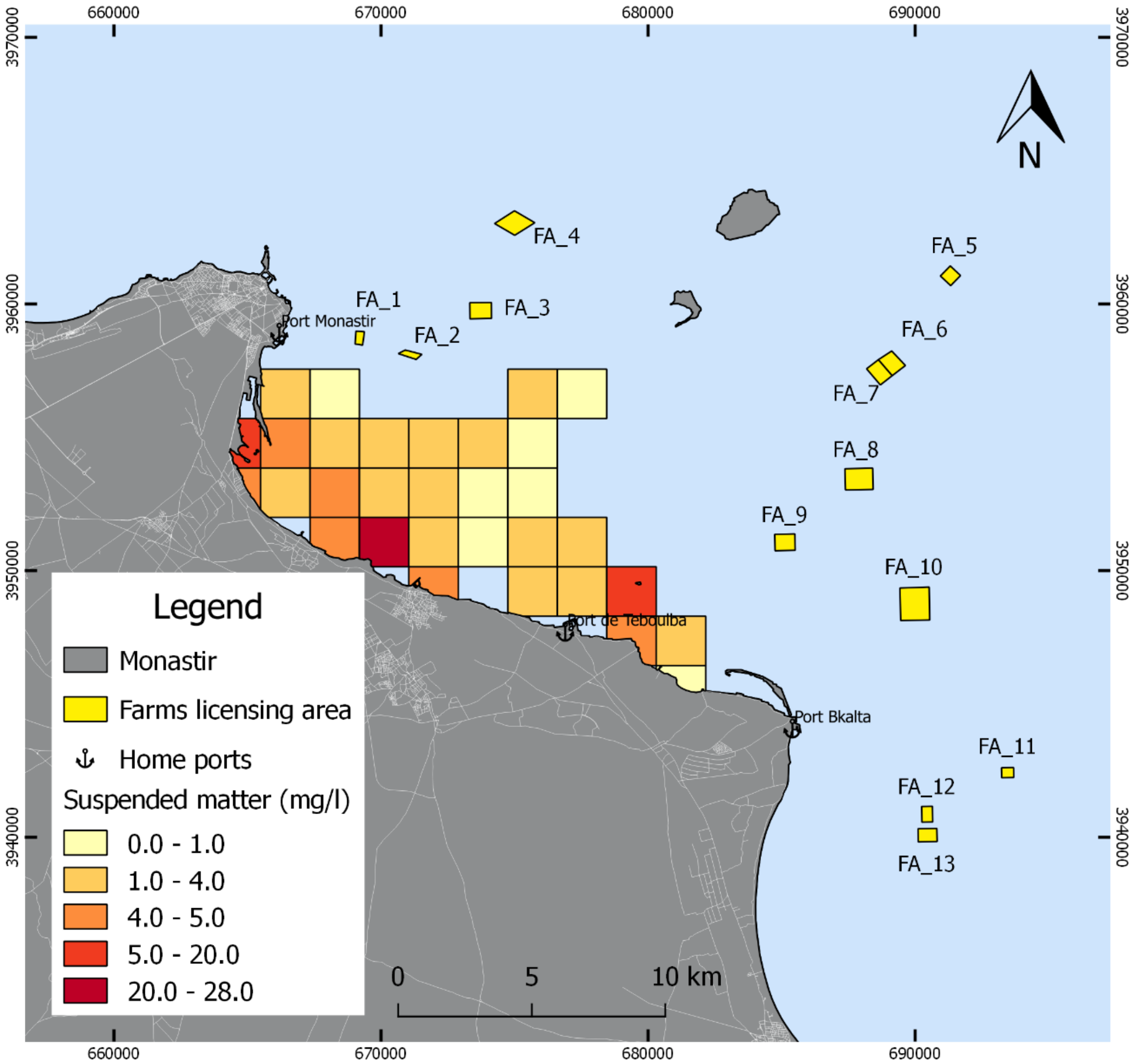

Figure 23: Suspended matter distribution map in the bay of Monastir, in mg/l.

3.2.2.6. Chlorophyll a

The Chlorophyll a values vary from 0 to 2.02 mg/l (Figure 24). The higher values appear near the coastline (Khniss, Ksibet el Mediouni, Sayada and Teboulba) and decrease according to the distance from the coast. It should be noted that top centre values (nearby aquaculture facilities) do not appear in the data collected.

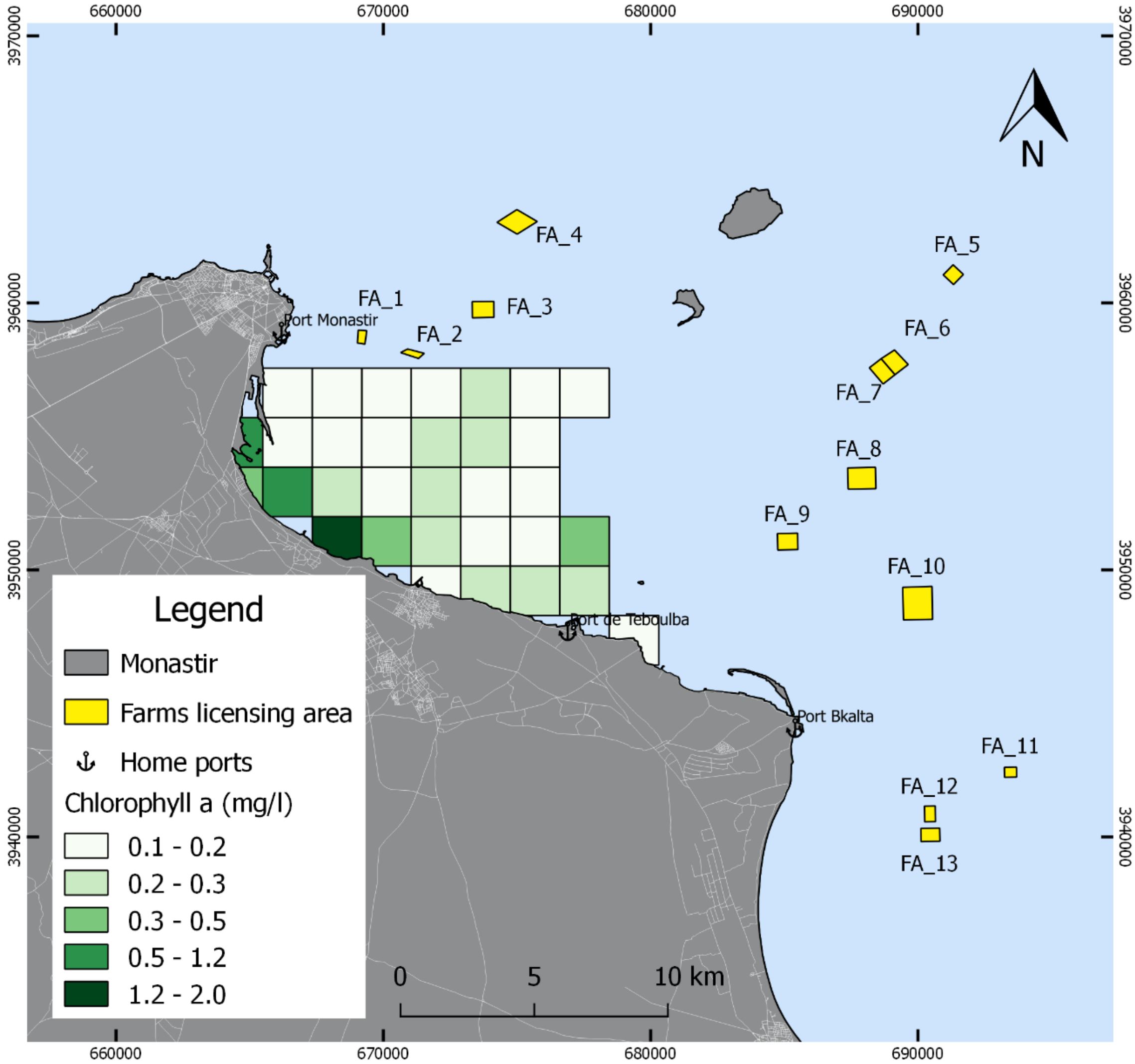

Figure 24: Chlorophyll a distribution map in the bay of Monastir, in mg/l.

3.3. Production carrying capacity (K)

3.3.1. Comparison between production carrying capacity and capacity given

After identifying the exposure of the area, distance and depth coefficients, production carrying capacity was calculated for each aquaculture facility (Table 21). The maximum production carrying capacity estimated is for FA_4, with a value of 2799 tonnes (per concession area). The minimum is for FA_12, with a value of 786 tonnes. The maximum production capacity per concession area given by the competent authorities, is for FA_4, with a value of 3000 tonnes. The minimum is for FA_5, with a value of 400 tonnes. The highest difference between production carrying capacity and capacity given has been detected in FA_7, where the capacity given (2500 tonnes) exceeds 1210 tonnes compared with production carrying capacity calculated (1290 tonnes). For the case of FA_8, the production carrying capacity (2130 tonnes) exceeds 1130 tonnes of the capacity given (1000 tonnes).

Table 21. Overview of production carrying capacities calculated. $\boldsymbol{f_a}$: Distance coefficient. $\boldsymbol{f_b}$: depth coefficient. $\boldsymbol{f_k}$: Exposure of the area. E: area (hectares). K: Production carrying capacity (tonnes). Capacity given: production capacity given by the competent authority (tonnes). K-capacity given and %: Difference between production carrying capacity and capacity given.

Farms	$\boldsymbol{f_a}$	$\boldsymbol{f_b}$	$\boldsymbol{f_k}$	E	K	Capacity given	K-Capacity given	% K and Capacity given
FA_1	2	0.9	1.5	45	1161	1300	-139.0	-11
FA_2	2	0.9	1.5	36	966.6	1700	-733.4	-43
FA_8	2	1	1.5	80	2130	1000	1130.0	113
FA_3	2	1	1.5	32	978	1000	-22.0	-2
FA_4	2	1.5	1.5	69	2799	3000	-201.0	-7
FA_6	2	1	1.5	45	1290	1650	-360.0	-22
FA_9	2	1	1.5	45	1290	480	810.0	169
FA_5	2	1	1.5	30	930	400	530.0	133
FA_7	2	1	1.5	45	1290	2500	-1210.0	-48
FA_11	2	1.5	1.5	45	1935	1500	435.0	29
FA_12	2	1	1.5	24	786	1600	-814.0	-51
FA_13	2	1	1.5	36	1074	1080	-6.0	-1
FA_10	2	1	1.5	-	-	1300	-	-

The last column of the table 21 corresponds to the percentage that should be change: the variation needed of the capacity given by the authorities, to fit these values to the production carrying capacity estimated. These variations are represented in the figure 25, where 3 farms have a percentage between -10 and 10 % (FA_3, FA_4 and FA_13). The farms which have to reduce more than a 10 % of the capacity given (to fit with K), are

FA_1, FA_2, FA_6, FA_7 and FA_12. The rest of them should increase their capacity to fit with K estimated (FA_8, FA_5, FA_11 and FA_9).

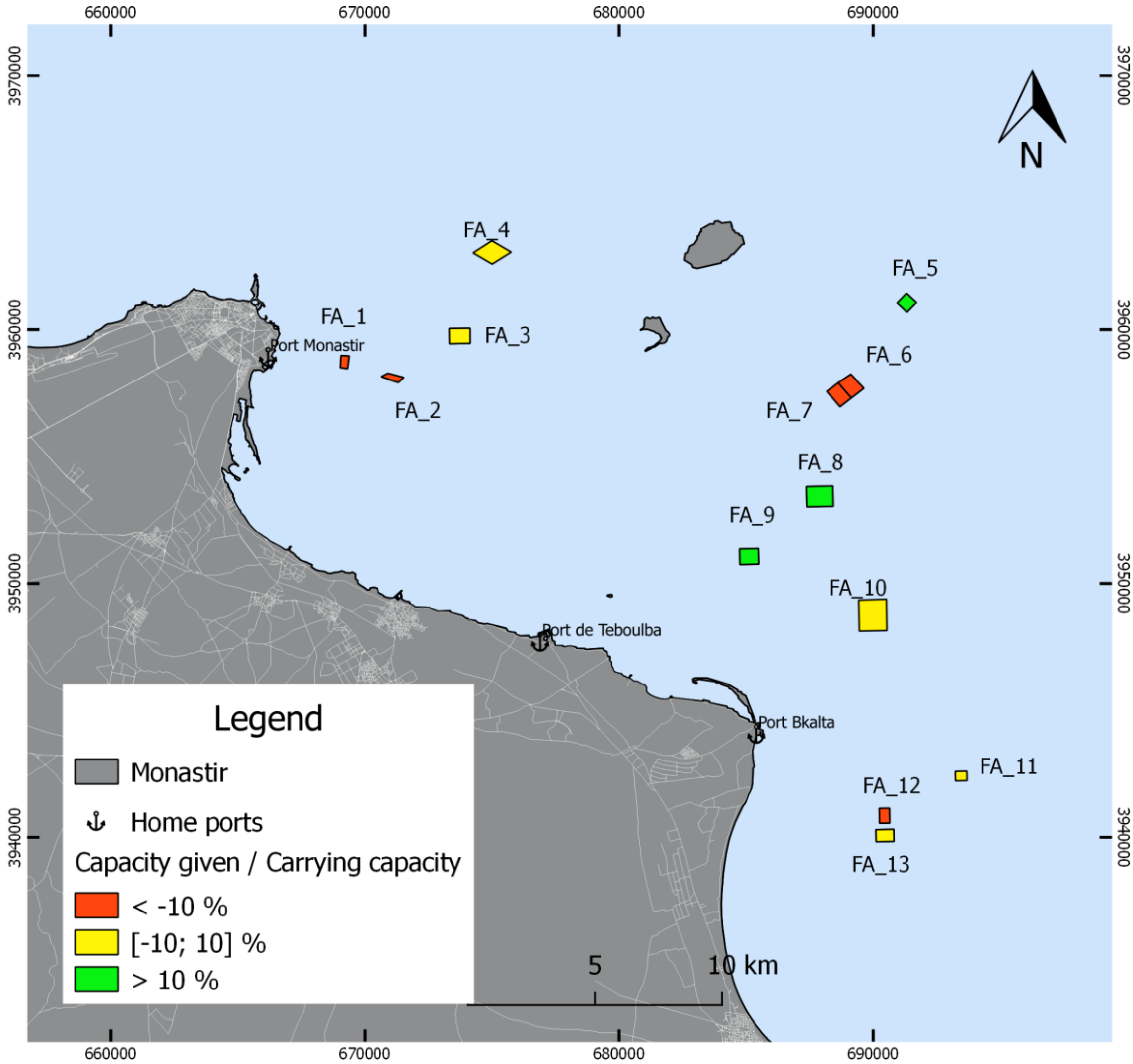

Figure 25: Variation (in percentage) of the capacity given needed to fit with the production carrying capacity (K) estimated. Red rectangles: farms who have to reduce their capacity. Yellow rectangles: farms more or less fit adjusted with K. Green rectangles: farms that should increase their capacity.

3.3.2. Comparison between production per zone and production carrying capacity

Real aquaculture production reached by the aquaculture facilities in 2016 were collected per zones (Table 22). In the area of Monastir, the production carrying capacity is 2127.6 tonnes and the real production reaches 2593 tonnes, which goes over the limit estimated. The production of these two farms should be reduced (21 %). Regarding the area of Teboulba, the real production (4340 tonnes) may increase by 59.47 % to reach the production carrying capacity estimated (10707 tonnes). The area of Bekalta can also increase its production (1045 tonnes) by 72.46 % to reach the production carrying capacity calculated (3795 tonnes).

Table 22. Overview of production carrying capacities calculated and real production per zones, in 2016. K per area: Production carrying capacity (tonnes). Real production: real farms production per zones (tonnes). %: Difference between production carrying capacity and real production.

Zones	Farms	Real Production	K per area	%
Monastir	FA_1	2593	2127.6	-21.87
	FA_2			
Teboulba	FA_8	4340	10707	59.47
	FA_3			
	FA_4			
	FA_6			
	FA_9			
	FA_5			
	FA_7			
Bekalta	FA_11	1045	3795	72.46
	FA_12			
	FA_13			

The figure 26 shows the needed variations of the real production to fit with the production carrying capacity estimated. The green and blue rectangles represent aquaculture facilities that can increase their production. The red rectangles represent two farms that should reduce their production to fit with the carrying capacity.

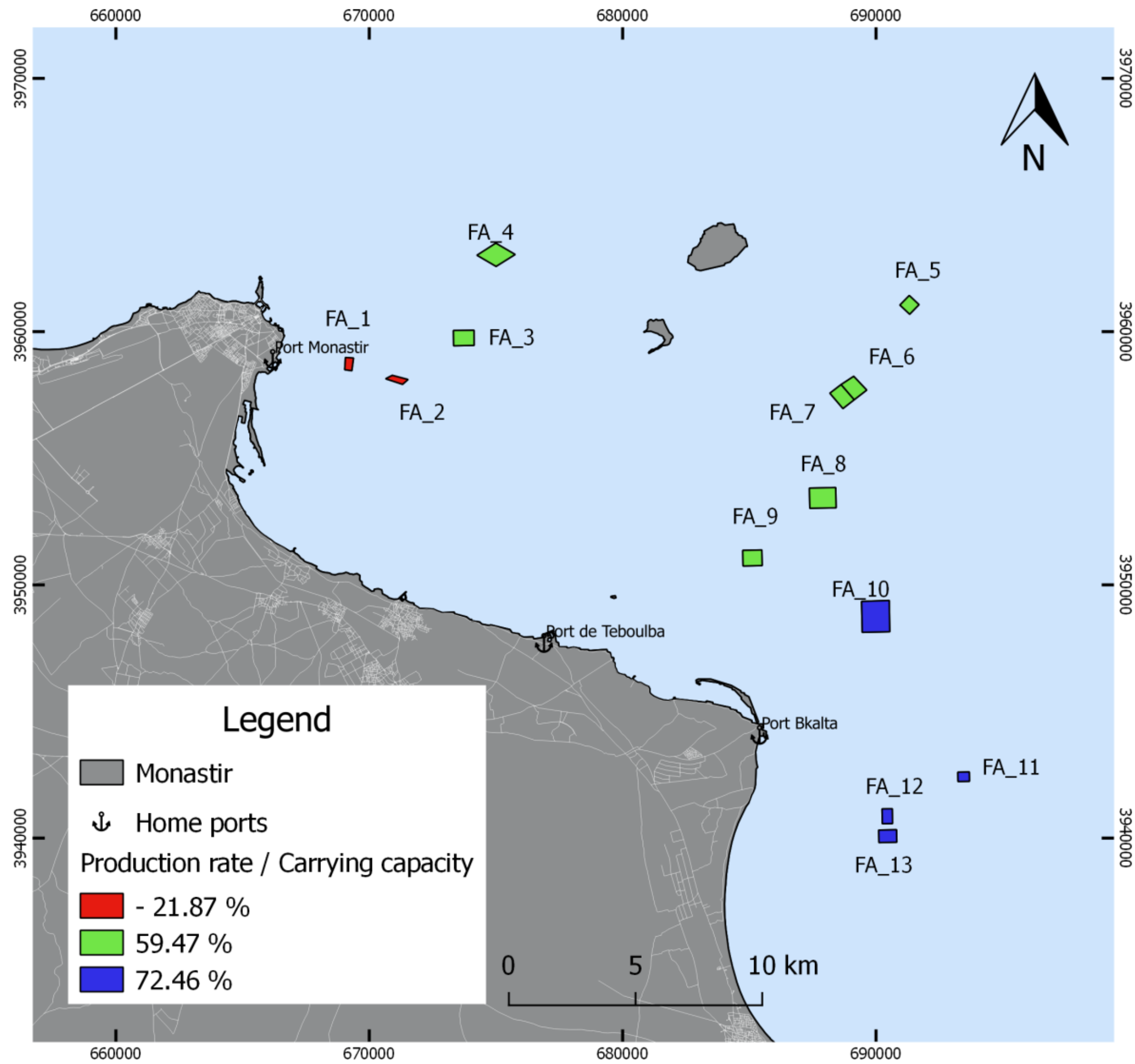

Figure 26: Variation (in percentage) of the real production needed to fit with the production carrying capacity (K) estimated. Red rectangles: farms who have to reduce their production (Area of Monastir). Green rectangles: farms that can increase their production (Area of Teboulba). Blue rectangles: farms that can increase their production (Area of Bekalta).

3.4. Allocated zones for aquaculture: compatibility analysis

3.4.1. Thematic maps and evaluation criteria (scenario 1 and 2)

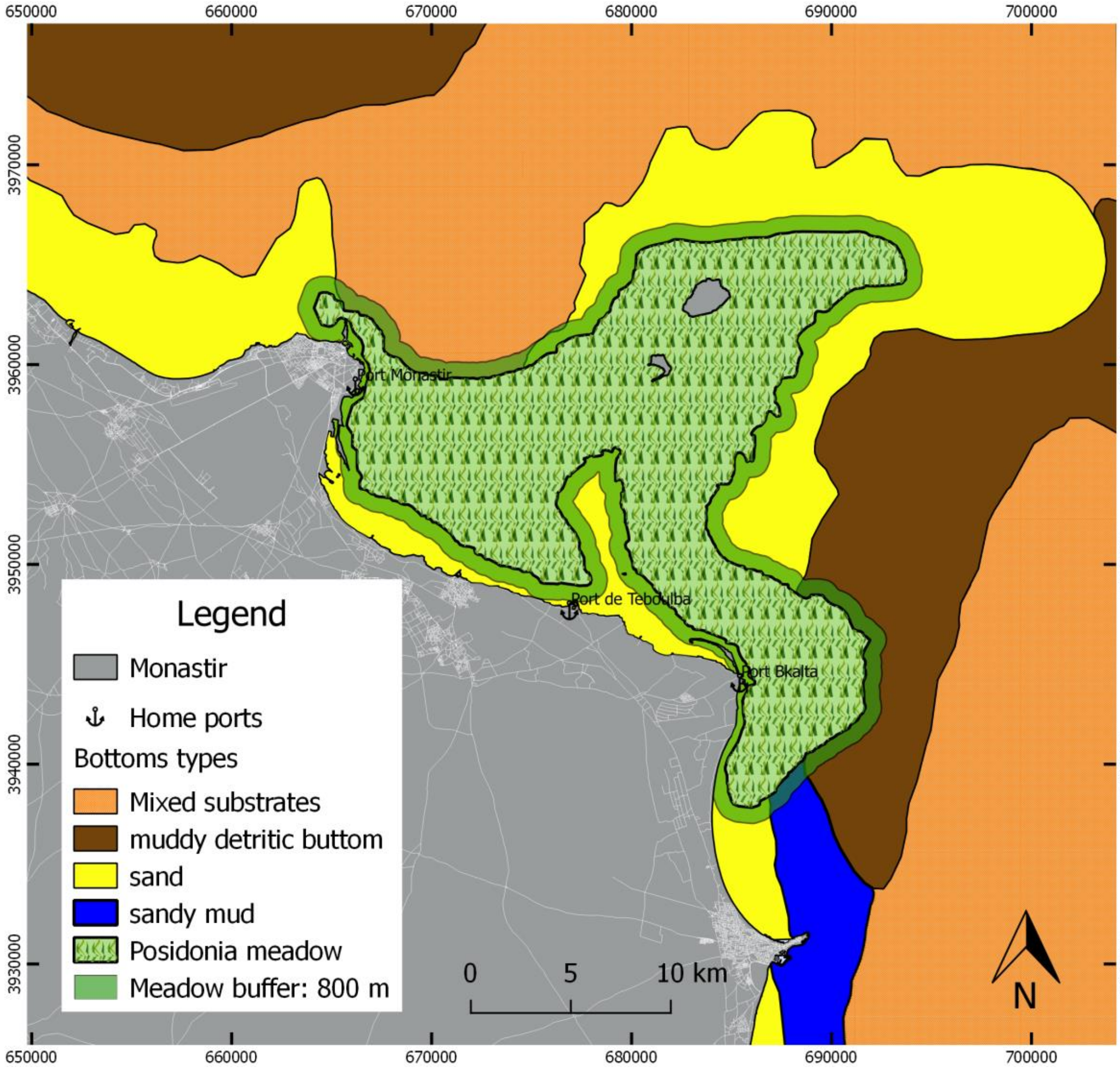

Figure 27. Bottom types of Monastir: Posidonia oceanica (buffer: 800 m), mixed substrates, sandy mud, Muddy detritic bottom and sand.

Bottom type has been considered as an evaluation criteria to analyse the compatibility of aquaculture facilities with sensitive areas, such as *P. oceanica* meadow. The figure 27 represents the bottom types in the bay of Monastir. The sand and muddy detritic bottoms are considered as suitable bottoms to locate sea cages (SI_{bt} = 1). Sandy mud and mixed substrates are considered moderately suitable (SI_{bt} = 0). *P. oceanica* meadow and its buffer zone of 800 meters are considered as incompatible bottoms to locate sea cages. These criteria have been integrated within the analysis to determine the suitability of each zones.

Basic parameters and administrative purposes have been considered with the aim to analyse the compatibility of aquaculture activities. Evaluation criteria applied were: bathymetry, distance from the shore, MPA, tourist areas, fishing grounds, farms licensing and discharge points. These criteria were mapped and overlapped (Figure 28), making layers operations according to their levels of interest.

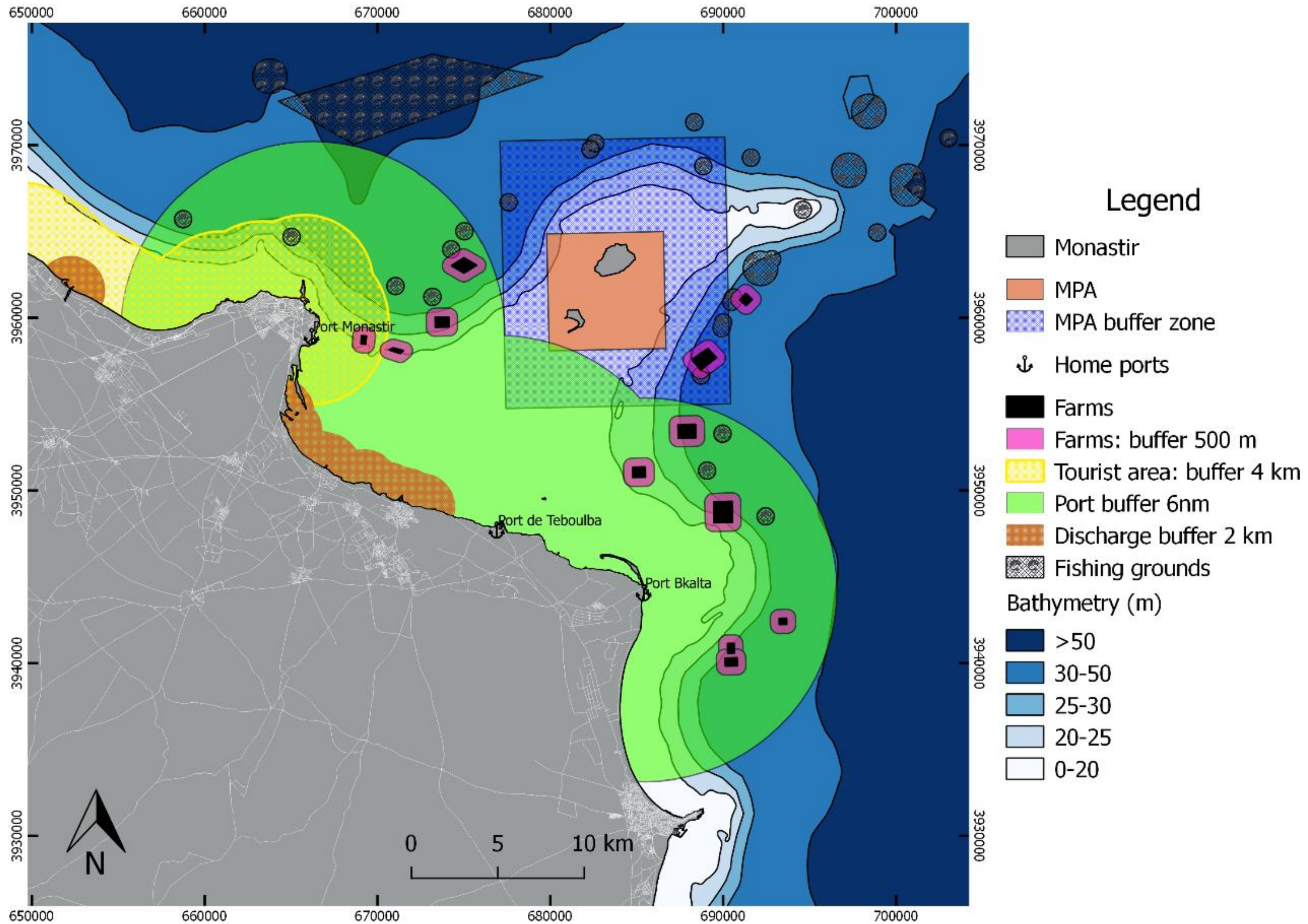

Figure 28. Compatibility analysis and mapping. Evaluation criteria: Basis parameters (Bathymetry and distance from the shore), administrative purposes (MPA, tourist areas, fishing grounds, farms licensing areas and discharge). For the scenario 2, port buffer was 10 nm.

3.4.2. Scenario 1: establishment of compatible zones for aquaculture

This Scenario and exercise has been done in order to overlap the available data in the area of Monastir with the existing farms.

The integration of basic parameters and administrative purposes in the evaluation criteria, and the application of theoretical models (e.g distribution of posidonia) , have allowed the establishment of three categories: *discordant zones* (where negative interaction are considered a risk and required additional information and reorientation in management activities), *compatible zones* (where apparently negative impacts or risks are not evident) and *moderately compatible zones* (where some evident negative impacts or risk are evident). The figure 29 represents the geographical location of these categories.

- The discordant zones are mainly delineated from the different administrative uses (MPA, fishing grounds, tourist areas), the bathymetry and the *P. oceanica* meadow (buffer 800 m). It is necessary to indicate that meanwhile the possibility to identify possible mitigation measures for the administrative use, the main risks in terms of impact is represented by the area of presence of *P. oceanica.* However, the information of this latter is not completed and the presence of the meadow is estimated from a predictive habitat map.
- Compatible zones are delineated from suitable bathymetry and optimal distance range from the shoreline (buffer 6 nm) and has an area of 20345.18 hectares.
- Moderately compatible zones fit with the rest of the bay where there is not inconsistence with other administrative uses (such as fishing grounds). These areas are characterized by potential limits which may influence the aquaculture sustainable growth.

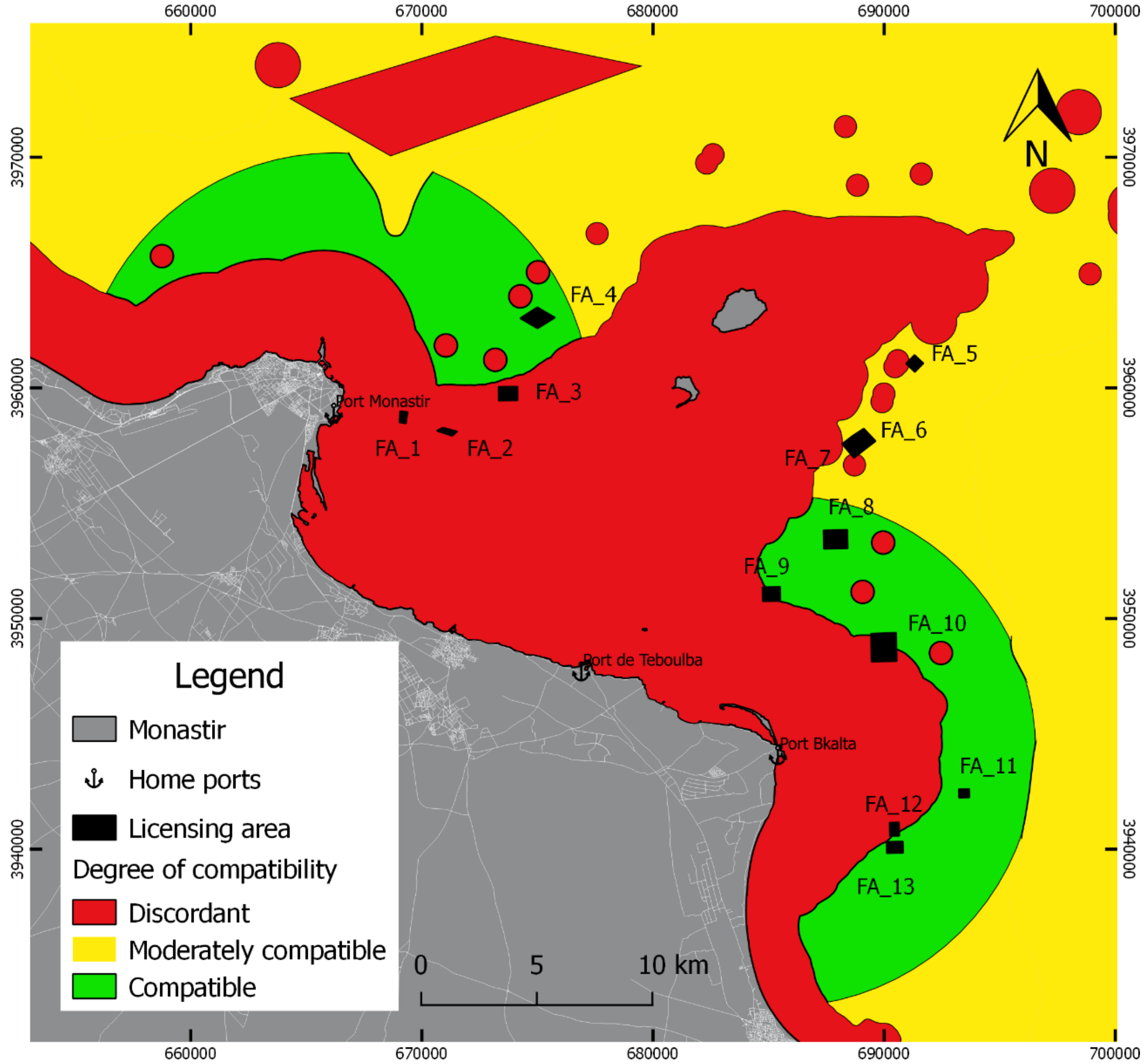

Figure 29. Establishment of compatible zones for aquaculture development and current situation concerning fish farming in the bay of Monastir.

Regarding the aquaculture facilities, only four of them are located within the compatible area (FA_4, FA_8, FA_11 and FA_13), six are located within the discordant area (FA_1, FA_2, FA_3, FA_9, FA_10 and FA_12) and three within the moderately compatible area (FA_5, FA_6 and FA_7). The results obtained and the farms located within the discordant area have to be more investigate.

With the aim to evaluate the possibility of adding more aquaculture facilities, another operation between layers have been done to exclude the current fish farming and its possible influence (Figure 30). The discordant area is higher due to the buffer (500 metres) applied around the farm licensing areas. The compatible area has now an area of 18855.96 hectares, 7.32 % less than the compatible area of the figure 29.

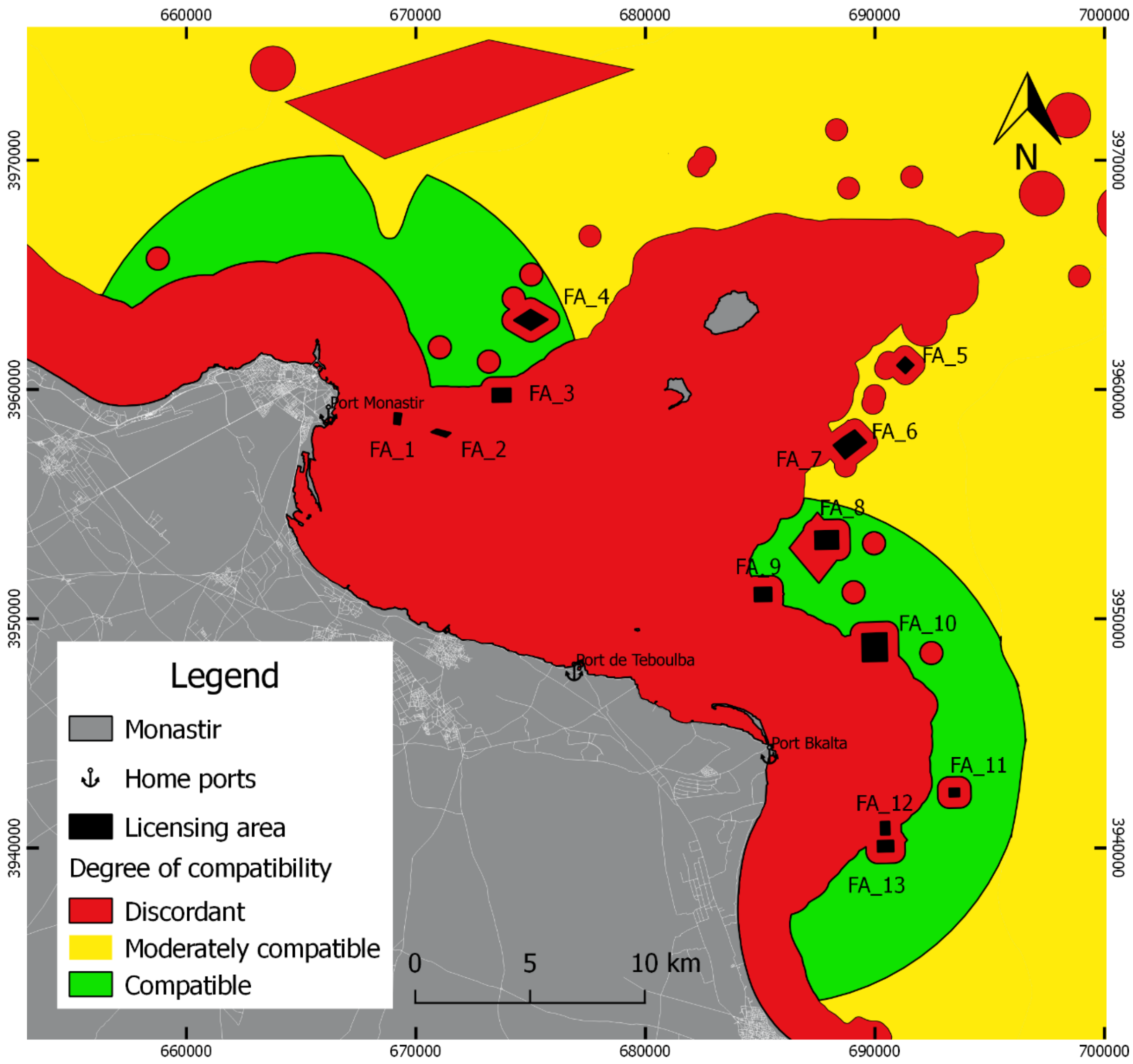

Figure 30. Establishment of compatible zones for aquaculture development, integrating location of current fish farming and its buffer zone (500 m) in the bay of Monastir.

3.4.3. Scenario 2: establishment of compatible zones for aquaculture

The integration of basic parameters (some coming from theoretical models) and administrative purposes in the evaluation criteria, has allowed the establishment of three main categories (Figure 31):

- Discriminant zone (-10000 to -30): represented in red.
- Moderately compatible zone (-30 to 30): represented in yellow
- Compatible zone (30 to 100): disaggregated in sub-categories.

The compatible zone (represented in green in the scenario 1) is disaggregated on the basis of the degree of compatibility estimations, where the weighting factor is incorporated. The suitability have been sub-categorized as follows:

- Degree of compatibility from 44 to 56: located on the top-right side of the Kuriat Islands.
- Degree of compatibility from 56 to 67: located within MPA buffer around the islands.
- Degree of compatibility from 67 to 78: located within MPA buffer around the islands and sandy bottoms. Other areas (upper right and left sides) are also categorized in this range of compatibility.
- Degree of compatibility from 78 to 89: two areas are detected within the port's buffer zone of 10 nautical miles.
- Degree of compatibility from 89 to 100: this range is the most suitable within the compatible zone. These areas are located within the port's buffer and within the sandy and muddy detritic bottoms.

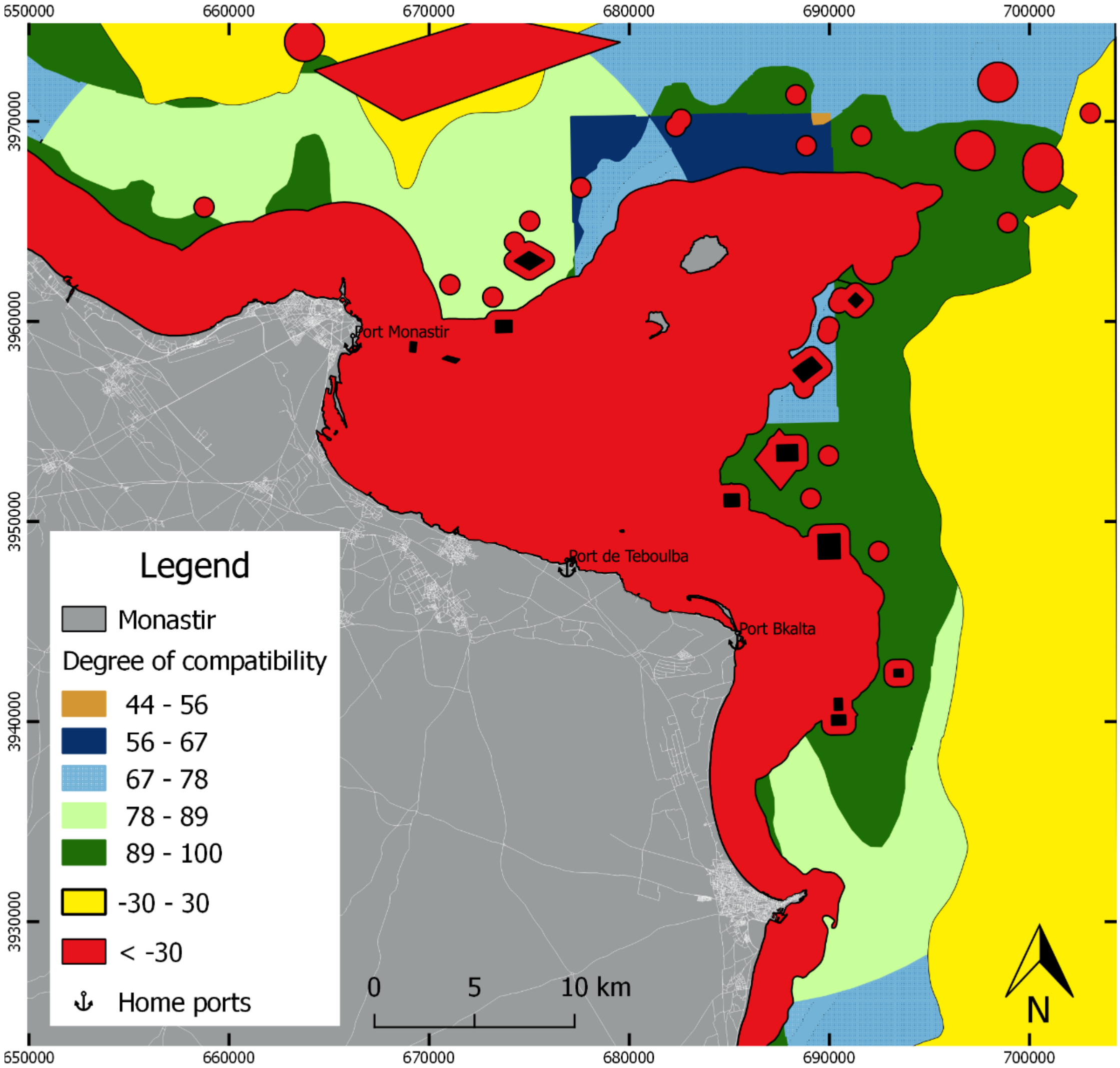

Figure 31. Establishment of compatible zones for aquaculture development in the bay of Monastir. Suitable zones are disaggregated by 5 ranges.

4. DISCUSSION

4.1. Study of the environmental and chemical conditions

The temperature of the sea can influence the harvesting time of the reared species such as seabass and sea bream: energy required for growth and to maintain a normal metabolism is directly linked to sea temperature (Ibarz *et al*., 2007). The bay of Monastir is a good area for fish farming, as its sea surface temperatures range between 13.6 ºC to 28.2 ºC. Farmed seabass and sea bream are generally harvested when they weigh 300 g to 500 g, which takes from a year and a half to two years, depending on water temperature. The sea temperature is relatively high and is within these species suitable temperature range (4 ºC to 32 ºC).

4.1.1. Potential negative environmental impacts on the aquaculture activity.

Coastal zones in terms of economic entity provide locations for activities such as agriculture, fishing, aquaculture, urban areas, industrial zones (manufacturing and/or extractive), tourist areas, maritime trades and ports, among many others. Due to the multiple uses and to the rapid urban growth in the coast of Monastir, an ecological disaster has occurred in 2006 and 2014 (El Khoja, 2014). This ecological disaster had negative repercussions, both at environmental and social levels: waste water plants were unable to refine all the waste flow, producing a high maritime pollution. The maritime pollution localized from Khniss to Sayada, caused a massive wild fish deaths, respiratory insufficiency and migraines to the inhabitants, provoked by the hydrogen sulphide coming from the sea.

Despite the need to obtain reliable and update data to measure the sea conditions, high nutrients concentrations areas were detected. Outbreaks of high values have been detected near the coastline, where there are large urban areas (Khniss, Ksibet el Mediouni, Sayada and Teboulba). In particular, there are 13 waste water discharge points (one corresponding to the river) near these urban areas. This anthropogenic impact has been studied to know how the state of the coastal habitat and water quality may affect the aquaculture production and food security. High values of nutrients, such as nitrates, nitrites and phosphates, can limit the chances of developing aquaculture in these zones. The discharge of organic and inorganic nutrients in marine ecosystems may produce a “hyper-nutrification” (eutrophication) and potential algal blooms. This can cause a high fish mortality in the sea cages (and also wild fish) due to gills damages and lack of oxygen (FAO, 1994). High levels of suspended matter and chlorophyll a are directly related to nutrients and sediments from the rivers and can also affect negatively the aquaculture development by reducing the water quality. The small concentration of dissolved oxygen can be caused by an organic enrichment of the ecosystem, which in turn, can form anoxic seabed.

4.1.2. Potential aquaculture impacts to the ecosystem

Economic losses due to severe aquaculture production decline are mainly due to the pollution caused by the proper farming system and other coastal uses, such as industries. Low levels of dissolved oxygen can be found on the seabed and on the water surface around the sea cages, due to the fish breathing needs and organic waste (such as pellets). This organic waste can also increase nutrient concentration rates in the areas nearby the farms, reducing the water quality (Figure 20). However, the EMP do not shows alarming values of nitrates, nitrites and phosphates (Table 20), only the suspended matters exceed the allowed levels by the Tunisian standards.

With the aim to analyse how environment affects the aquaculture facilities and vice versa, more information and data are required: EMP from all the farms to have a clear overview to the environmental conditions (since the farms were created) and environmental information on the rest of the bay of Monastir (with a temporal replication).

4.2. Adjustment of the capacity given and real production

The capacity given by the competent authorities should be modified according to the results highlighted on the table 20 and figure 26. In particular, five farms could have a lower allowed capacity, four could have a higher capacity and only three farms fit to their production carrying capacity. Competent authorities should evaluate the capacity of the future installations taking into account environmental and economic factors with the aim to adapt each farm concessions to the specific environmental needs of the site.

The real production should be adjusted according to the results showed on the table 21 and figure 26. In this case, only one zone (Monastir) exceeds the production carrying capacity limit. The fact that the other zones (Bekalta and Teboulba) could increase their real production by more than 50 %, highlights that there is another type of problem. This problem can be related to internal financial issues, to sales, few inputs or cages or to high mortality due to diseases, among others. In the absence of real production data detailed by farms, it is impossible to determine the real cause of the low production detected in these zones.

4.3. Allocated zones for aquaculture in the Bay of Monastir

According to the theoretical model used to delineate the *P. oceanica* meadow in the bay of Monastir, its extension covers from shallow water to Kuriat Islands (5 m to 27 m). This ecosystem is very important as it plays a critical and special role in the biodiversity of an area, coastline protection from erosion and it is particularly considered as a good bio-indicator to sea water quality. Consequently, this sensitive habitat has been taken into account in the analysis to avoid potential negative impacts and to reduce *P. oceanica* meadow degradation by introducing sea cages nearby (< 800 m) or above the meadow. In view of the above and having regard to the existing farms location, it would be necessary to move six aquaculture facilities: FA_1, FA_2, FA_3, FA_12, FA_8 and FA_10.

Aquaculture and the tourism sector are two activities that compete with one another for the space and the use of coastal waters (Luque and Martin, 2010). Two aquaculture facilities could have a negative visual impact because of its closeness to the coastline. In particular, these aquaculture facilities (FA_1 and FA_2) are located in front of the tourist area (hotels, tourist beaches and leisure port of Monastir) and could not be accepted by in the two activities are not integrated. To avoid this visual impact, a buffer zone (4 km) around the coast have been considered and included in the analysis.

Artisanal fishery is an important sector in the bay of Monastir, both social and economic point of view. The existence of sea cages has led to conflicts among the sectors. The missions carried out highlighted the discontent of the fishermen due to the farms location, causing catch reduction, and unloading points at their home ports. The problem may be due to the lack of regulation or not taking into account artisanal fishery areas, delivering farms licensing areas.

Creating an agreement between fishermen and aquaculture producers is essential and could mitigate local conflicts, in which fishermen could fish within the farm beaconing area. Furthermore, some aquaculture production methods can be easily transferred to artisanal fishermen: seaweed, sea cucumber, corals or shellfish among others, that can operate with low running costs and no feed inputs (Le Gouvello *et al*., 2017). The agreement and the production transference could avoid conflicts among artisanal fisheries and aquaculture.

Through the establishment of an AZA in the bay of Monastir, aquaculture interest could be directly aligned with the MPA objectives: maintain good water quality. MPA could share the area with an environmentally compatible economic activity in order to provide sustainable financing. Finfish farming may have negative socioeconomic impacts because of the potential impacts related to nutrient and chemical discharge, diseases and escapees among others, if badly managed and located. However, shellfish farming is considered as more environmentally-friendly: net removal of nutrients from the water. This aquaculture type could provide opportunities for greater synergies within the MPA use providing alternative livelihoods (Le Gouvello *et al*., 2017). Besides, MPAs or zones that allows sustainable commercial or recreational fishing and farming are defined as Categories V and VI (Day *et al*., 2012), in which MPAs may be necessary to allow extractive activities with the aim to provide sustainable financing and to improve their logistics. However, aquaculture activities require special authorization in protected areas, in which the licensing area requirements within an AZA should be linked with MPAs objectives and an adequate EIA (Sánchez-Jerez *et al.*, 2016). Developing an integrated multi-trophic aquaculture (IMTA) in the MPA (both restricted area and buffer zone), within the context of AZAs, should represents an opportunity to enhance sustainability, social acceptability of the aquaculture sector and economic benefits for both aquaculture producers and MPA financing. Shellfish and seaweed farming can mitigate coastal and finfish farming eutrophication, regulate nutrient discharge (Filgueira *et al.,* 2015) and restore benthic habitats.

The areas within the range of degree of compatibility from 44 to 78 (around the Kuriat Islands and within the MPA buffer) estimated in the scenario 2 (Figure 31), could be the more suitable zone to implement new finfish and shellfish farms and to create an IMTA (within AZA).

Combining existing finfish farms and their waste generated, with organic and inorganic species that extract dissolved inorganic nutrients and particulate organic matter, the environmental impact of finfish farming could be mitigated. According to the scenario 1, the best aquaculture facility to create an IMTA could be FA_4, due to the currents direction and to its location within the compatible zone.

Besides, FA_1 and FA_2 will be relocated due to their visual impact, shallow installation and *P. oceanica* meadow. The local aquaculture multi-stakeholder platform (MRCA) have taken into account these impacts generated by these two farms and a new licensing area proposal is under way. The lack of information regarding the future location of these new licensing areas, suggest to propose a new licensing area within the MPA buffer zone and to combine this production system with shellfish farming.

The compatible zones obtained in the scenario 2 are bigger than the scenario 1 due to the integration of the weighting factor to estimate the degree of compatibility. The scenario 2 takes into account more variables and ranges. The results obtained are therefore more detailed and is more relevant with respect to social and environmental dimensions.

However, the port distance weighting factor should be higher to give more economic realism: the home port distance is an important factor to reduce production costs. It is difficult to have a sustainable economic development in areas located in the 67 – 78 (in the upper right side of the study area) zones due to their remoteness.

5. CONCLUSIONS

Aquaculture sector in the bay of Monastir has grown rapidly since 2008 and this created important opportunities for the local communities in terms of positive economic and employment impact. However based on the result and analysis of the data collected and the models applied some consideration could to be done in order to identify further steps and facilitate and support this process of development.

Some conflicts among maritime space users are evident and have been generated due to the location of some existing farms. The main conflict detected was among fishermen and aquaculture producers because of the farm licensing area and fishing grounds location.

Urban and industrial coastal pollution might increase the risk of harmful algal blooms and have a negative impact to aquaculture. Aquaculture facilities have to realize an EMP to measure all the parameters of water (and sediments) quality that could be altered with this activity. The EMP results can be used to reduce the potential impact on the environment related to aquaculture production, such as high level of suspended matter.

Based on the predictive model applied (EuSeaMap, 2016) that identified the distribution of Posidonia, the discordant zones detected have been mainly delineated using the *Posidonia oceanica* meadow extension and its buffer zone of 800 meters. Due to the scarce reliable data and information, this extension was obtained through a predictive model. Consequently, further research is required to obtain the current meadow extension among others.

The production carrying capacity was estimated by applying a formula used in Greece (Karakassis *et al.,* 2013) that takes into account the area of licensing, depth, bay's morphology and shoreline distance. The capacity given is rarely in line with the carrying capacity estimated.

The production of each farm of the bay was grouped per area. Comparing the production carrying capacity per zone with the real production, some areas have the possibility to increase their production.

Some farms were detected within the suitable areas estimated in both scenarios. The scenario 1 have taken into account less parameters and ranges. The port distance used has been the main determining factor separating compatible and moderately compatible areas.

The scenario 2 have taken into account more parameters and ranges to calculate the degree of compatibility. The weighting factor have been used to categorize the suitable area. This area is more detailed, however is less reliable: for instance, the area so far from the shoreline detected as suitable.

According both scenarios, there are areas available in the bay of Monastir to the establishment of more farms. However, further analysis are required to verify and redefine these areas with current and reliable data.

6. FOLLOW UP AND SUGGESTIONS

Environmental monitoring in the area requires an improvement in coordination among different authorities and producers to enhance effectiveness of EMP itself. Monitoring results and health concerns related with pathologies should be shared by producers due to the vicinity of farms to minimise the risk of transmission of diseases between them. In fact, improving the share of information and increasing the communication, producers could benefit from the expertise performing an integrated risk management and assessment of the whole bay. It is necessary to have more detailed information on the presence and extension of the *P. oceanica* meadow, this information could give us more accurate information on the potential impact of aquaculture on this important habitat and the definition of the discordant areas.

The interaction of artisanal fisheries and with aquaculture must be more analysed and a more greater participation of artisanal fisheries in the local aquaculture multi-stakeholder's platform need to be more considered within the future AZA management plan. This would be necessary to avoid any kind of possible and future conflicts or negative interaction. To that end, it is necessary to collect landing data from all the ports in the study area: temporary data series (2000-2016) of landings broken down by species group. Seeing the historical evolution of the landings (before and after aquaculture development in Monastir) can help to understand the relation between activities, solve their potential conflicts and could be used as social indicator in order to establish the AZA. As well as better integration of artisanal fisheries with the aquaculture development is necessary and this could be done also by the implementation of specific programme such the development of shellfish farming after appropriate studies or by allowed the fisherman to catch in the areas of cages were there are a concentration of wild fishes. For this latter a specific programme could be applied.

A plan of mote integration of tourism with the aquaculture activities could be carried also in consideration of the MPA identified.

To evaluate if the bay of Monastir could support more aquaculture facilities, an evaluation of the carrying capacity should be done: environmental, physical carrying capacity and a new production carrying capacity with reliable data and information.

Furthermore, it is important to review all the discordant zones and to further investigate due to the missing data.

To add or to relocate aquaculture facilities towards compatible zones preselected in the bay of Monastir, competent authorities and aquaculture producers should:

- Analyse of aquaculture potentialities, taking into account cost/benefits and potential market access.
- Further investigate the discordant zones.
- Management and monitoring plans have to be done.
- Integrate the AZA in the legal framework: local regulation.
- Prepare technical document in support to the establishment of the farm (EIA, production plan, EMP, economic and financial reports).

The AZA's management plan should also include elements for Better Management Practices to be developed and shared among farmers.

A second step of this study is underway between the GFCM and the national authorities of Tunisia in order to define the best appropriate method for the improvement of farms allocation and implementation of the AZA including the implementation of and EMP and application of sustainable indicators (economic, social and environmental) to monitor aquaculture activities in the area of Monastir.

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Annex 1. Resolution GFCM/36/2012/1 on guidelines on Allocated Zones for Aquaculture (AZA)

The General Fisheries Commission for the Mediterranean (GFCM)

RECOGNIZING that aquaculture plays an important role in terms of contribution to economic development and it represents an important source of food and employment for coastal communities of GFCM Members;

CONSISTENT WITH the 1995 FAO Code of Conduct for Responsible Fisheries, in particular Article 9 which calls upon States, *inter alia*, to produce and regularly update aquaculture development strategies and plans, as required, to ensure that aquaculture development is ecologically sustainable and to allow the rational use of resources shared by aquaculture and other activities;

TAKING INTO ACCOUNT relevant provisions in the Johannesburg Declaration on Sustainable Development of 2002 and the 1995 Convention for the Protection of the Marine Environment and Coastal Region of the Mediterranean and its Protocols as amended, in particular, the Protocol on Integrated Coastal Zone Management (ICZM);

NOTING that aquaculture activities are rapidly expanding in the GFCM Area, thus calling for an ICZM consistent planning and management at regional level;

ACKNOWLEDGING that aquaculture activities affect and are affected by other human activities to the extent that their relative contribution to environmental degradation needs to be controlled and adverse social and environmental interactions with aquaculture activities have to be reduced;

CONSIDERING the implementation of a regional strategy for the creation of Allocated Zones for Aquaculture (AZA) as an immediate priority for the responsible development and management of aquaculture activities in the Mediterranean and Black Sea;

FURTHER CONSIDERING that the creation of AZAs may facilitate the integration of aquaculture activities into coastal zone areas exploited by other users and contribute to the enhancement of coordination between the different public agencies involved in aquaculture licensing and monitoring processes;

ACKNOWLEDGING conflicts between aquaculture activities and other users of the coastal zone in addition to the main variables and factors affecting the development of aquaculture activities,

STRESSING IN PARTICULAR the need for the definition of common criteria for the selection of sites for aquaculture activities, *BEARING IN MIND* that the sustainable development of aquaculture can be significantly facilitated by a clear vision of Allocation Zones for Aquaculture (AZAs);

DESIRING to promote in the GFCM area of competence the establishment of AZAs as a management tool for marine spatial planning;

ADOPTS, in conformity with the provision of Article III paragraph 1 (h) of the GFCM Agreement, that:

1. Contracting Parties and Cooperating non-contracting Parties of the GFCM (hereafter referred to as CPCs) shall include in their national marine spatial planning strategy of aquaculture development and management schemes for the identification and allocation of specific zones reserved for aquaculture activities.

2. AZAs shall comprise specific areas dedicated to aquaculture activities, and any future development thereof and their identification shall be based on the best social, economic and environmental information available in order to prevent conflicts among different users for increased competitiveness, sharing costs and services and to assure investments.

3. AZAs shall be established within the remit of local or national aquaculture plans of CPCs with the aim of ensuring the sustainability of aquaculture development and of promoting equity and resilience of interlinked social and ecological systems.

4. AZAs shall be established within the framework of ICZM, with regulations and/or restrictions being assigned to each zone in accordance with their degree of suitability for aquaculture activities and carrying capacity limit.

5. The zoning process for the establishment of AZAs shall follow a participatory approach, be transparent, coordinated by the main authority responsible for marine planning at local level and carried out in cooperation with the different authorities involved in the aquaculture licensing and leasing procedures and monitoring. The coordination of competences among the different public authorities involved in aquaculture licensing and leasing procedures and monitoring shall be ensured at national level.

6. Zones to be allocated to aquaculture activities shall be classified, inter alia, as, “areas suitable for aquaculture activities”, “areas unsuitable for aquaculture activities” and “areas for aquaculture activities with particular regulation and/or restriction”; guidelines shall be developed to this end;

7. AZAs, once established, shall be based on legal and regulatory provisions integrated into the national legislation or other adequate national administration level and on inter-ministerial coordination in order to ensure their effective implementation.

8. For every AZA, an allowable zone of effect of aquaculture activities could be defined in the close vicinity of each farm. Such zone shall be accompanied by a Environmental Monitoring Programme.

9. The Environmental Monitoring Programme shall be flexible and adaptable, taking into account scale (time and space) approach, and monitoring shall be mandatory.

Annex 2. Licensing area and beaconing coordinates for each farm. Coordinates in decimal degrees. Card: Cardinal. N/N1/N2: North. S/S1/S2: South. E: East. W: West

Farms	Licensing area coordinates		Beaconing coordinates		
	Longitude E	Latitude N	Cardinal points	Longitude E	Latitude N
FA_1	10.87017	35.76033			
	10.86963	35.75602	Card N1	10.86817	35.76483
	10.87272	35.75560	Card N2	10.88475	35.7593
	10.87357	35.76010	Card E	10.89017	35.7516
FA_2	10.88742	35.75250	Card S1	10.88217	35.7465
	10.89033	35.75367	Card S2	10.86783	35.753
	10.89718	35.75208	Card W	10.85983	35.75816
	10.89475	35.75042			
FA_8	11.07138	35.71055	Card N	11.07283	35.718
	11.08278	35.71055	Card E	11.087	35.70416
	11.08278	35.70333	Card S	11.07283	35.69
	11.07138	35.70333	Card W	11.05883	35.70416
FA_3	11.91680	35.76500			
	11.92580	35.76500			
	11.92570	35.75967			
	11.91675	35.75967			
FA_4	10.93667	35.79167	Card N	10.93667	35.80383
	10.94500	35.79583	Card E	10.94867	35.79583
	10.93667	35.80000	Card S	10.93667	35.79
	10.92833	35.79583	Card W	10.925	35.79583
FA_6	11.08610	35.74717	Card N	11.08861	35.75416
	11.09167	35.75000	Card E	11.10194	35.744
	11.09722	35.74500	Card S	11.08861	35.7361
	11.09167	35.74167	Card W	11.07528	35.744
FA_7	11.08611	35.74722	Card N	11.08861	35.75416
	11.09167	35.74167	Card E	11.10194	35.744
	11.08667	35.73861	Card S	11.08861	35.7361
	11.08111	35.74417	Card W	11.07528	35.744
FA_9	11.04167	35.68889	Card N	11.04583	35.6938
	11.05000	35.68889	Card E	11.05611	35.6861
	11.05000	35.68333	Card S	11.04583	35.677
	11.04167	35.68333	Card W	11.03611	35.6861
FA_5	11.11250	35.77500	Card N	11.11667	35.78183
	11.11667	35.77833	Card E	11.12443	35.775
	11.12083	35.77500	Card S	11.11667	35.76805
	11.11667	35.77167	Card W	11.10833	35.775
FA_11	11.13333	35.60500			
	11.13833	35.60500			
	11.13833	35.60833			
	11.13333	35.60833			

Farms	Licensing area coordinates		Beaconing coordinates		
	Longitude E	Latitude N	Cardinal points	Longitude E	Latitude N
FA_13	11.09833	35.58833	Card N	11.1025	35.59916
	11.10611	35.58833	Card E	11.11278	35.5883
	11.09833	35.58389	Card S	11.10194	35.57972
	11.10611	35.58389	Card W	11.09167	35.5883
FA_12	11.10000	35.59583	Card N	11.1025	35.59916
	11.10444	35.59583	Card E	11.11278	35.5883
	11.10444	35.59056	Card S	11.10194	35.57972
	11.10000	35.59056	Card W	11.09167	35.5883
FA_10	11.09300	35.66983			
	11.10500	35.66983			
	11.09300	35.65883			
	11.10500	35.65883			

Annex 3. Selected list of persons met during the field missions.

N	Name	Title	Affiliation
1	Adel Khabthani	Governor of Monastir	Government of Monastir
2	Houssam Hamza	Head of Mission to the Agriculture and Fishing resources Minister	MARHP
3	Rakia Belkahia	Assistant Director-General for the Aquaculture	DGPA
4	Foued Mestiri	-	CTA
5	Hamadi Ben Rhouma	Commandant of the port (Monastir)	APIP
6	Mehdi Chaka	Veterinary Doctor	CRDA Monastir
7	Zahia Zidi	Administrator in the Governorate of Monastir	Government of Monastir
8	Ridha Amimi	Fisheries and aquaculture - district chief	CRDA Monastir
9	Mourad Zouari	Regional Director	CTA
10	Hechmi Missaoui	Director	INSTM
11	Mehrez Baste	Director	DGPA
12	Mohamed Hammami	Director	CTA
13	Anoir Nouira	Fisherman	UTAP
14	Mahdi Soula	Veterinarian	CTA
15	Foued Nakbi	Aquaculture producer	PRIMAFISH
16	Amel Mzoughi	Aquaculture producer	PRIMAFISH
17	Ezzdine Souissi	Aquaculture producer	HANCHIA FISH
18	Oussama Mdimegh	Aquaculture producer	TTF-TSF
19	Azmi Ben Tkaya	Aquaculture producer	AQUASUD

Annex 4: Survey for Tunisian competent authorities, realized to compile aquaculture information and data in the bay of Monastir: social (INDSOC), economic (INDECO), environmental (INDENV) and governance (INDGOUV) indicators.

Code			2008	2009	2010	2011	2012	2013	2014	2015	2016
INDENV_1	Taux de conversion alimentaire	Loup Daurade Maigre									
INDENV_5	Poissons fugitifs (nombre estimé)										
INDENV_3	Quantité d'antibiotiques (kg) Quantité d'antiparasitaire (kg)										

Code		OUI	NON	En cours	Si oui, préciser	
INDENV_4	Existence d'un système de suivi pour évaluer le niveau d'impact des cages sur les habitats et communautés benthiques				Années de préparation	
					Année de mise en place	

Code		OUI	NON	En cours	Si oui, préciser	
INDENV_2	Existence dans la réglementation nationale de dispositions spécifiques sur le choix des sites aquacoles visant à préserver la biodiversité et les habitats sensibles				Années de préparation	
					Année de mise en place	
					Réglementation	
	Existence de critères de profondeur (m) pour l'implantation de cage appliqués au choix des sites en rapport avec la densité d'élevage				Années de préparation	
					Année de mise en place	
					Profondeur (m)	
					densité de poissons (kg/m3)	
INDENV_3	Existence de programmes nationaux de suivi de l'usage des produits chimiques dans l'aquaculture				Années de préparation	
					Année de mise en place	
INDENV_4	Existence dans la réglementation nationale de dispositions spécifiques imposant un système de suivi pour évaluer le niveau d'impact des cages sur les habitats et communautés benthiques				Années de préparation	
					Année de mise en place	
INDENV_5	Existence de programmes nationaux de suivi des fugitifs				Années de préparation	
					Année de mise en place	

Code				2008	2009	2010	2011	2012	2013	2014	2015	2016
INDECO_1	Valeur de production Loup	Volume production (t) Prix départ ferme de l'espèce										
	Valeur de production Daurade	Volume production (t) Prix départ ferme de l'espèce										
	Valeur de production Maigre	Volume production (t) Prix départ ferme de l'espèce										
	La société aquacole	Coût de production (DT) Bénéfices de la ferme (DT) PIB (Produit Intérieur Brut, déflateur)										
INDECO_2	Parité des prix/intrants Loup	Prix unitaire moyen du produit (DT/kg)										
		Prix unitaire moyen (DT/kg)	Aliments									
			Alevins									
	Parité des prix/intrants Daurade	Prix unitaire moyen du produit (DT/kg) au départ ferme										
		Prix unitaire moyen (DT/kg)	Aliments									
			Alevins									
	Parité des prix/intrants Maigre	Prix unitaire moyen du produit (DT/kg) au départ ferme										
		Prix unitaire moyen (DT/kg)	Aliments									
			Alevins									

Code		OUI	NON	En cours	Si oui, préciser	
INDECO_3	Existence de système de certification de la qualité				Années de préparation	
					Année de mise en place	
INDECO_4	Orgnisations d'exploitants Aquacoles (Associations ou coopératives				Années de préparation	
					Année de mise en place	
		<300 g	300-400 g	400-600 g	>600 g	
INDECO_5	Tailles de vente Loup (%)					
	Tailles de vente Daurade (%)					
	Tailles de vente Maigre (%)					

Code			2008	2009	2010	2011	2012	2013	2014	2015	2016
INDSOC_1	Importations de poisson	Loup Daurade Maigre									
	Exportations de poisson	Loup Daurade Maigre									
	Production nationale de poisson	Loup Daurade Maigre									
INDSOC_3	Budget (DT) des organisations d'exploitants aquacoles consacré à la promotion et à l'image de l'aquaculture	Si il n'y a pas d'organisation: budget de l'entreprise									

	Budget (DT) total des organisations d'exploitants aquacoles	Si il n'y a pas d'organisation: budget de l'entreprise									

Code		OUI	NON	En cours	Si oui, préciser	
INDSOC_2	Existence de systèmes de traçabilité, de certification et d'étiquetage				Années de préparation	
					Année de mise en place	
INDSOC_4	Existence de syndicats d'exploitants aquacoles				Années de préparation	
					Année de mise en place	
	Existence d'organisations d'exploitants aquacoles				Années de préparation	
					Année de mise en place	
	Existence de conventions collectives aquacoles (CCA) au niveau national				Années de préparation	
					Année de mise en place	
INDSOC_6	Existence au niveau national d'une loi/réglementation en faveur de l'égalité des sexes au travail				Années de préparation	
					Année de mise en place	
	Mesures en place au niveau national pour aider les travailleurs à équilibrer leur vie personnelle et professionnelle				Années de préparation	
					Année de mise en place	

<table>
<tr><th>Code</th><th></th><th></th><th>2008</th><th>2009</th><th>2010</th><th>2011</th><th>2012</th><th>2013</th><th>2014</th><th>2015</th><th>2016</th></tr>
<tr><td rowspan="9">INDSOC_6</td><td rowspan="7">Nombre d'employés</td><td>Nombre total de personnes employés</td><td rowspan="9"></td><td rowspan="9"></td><td rowspan="9"></td><td rowspan="9"></td><td rowspan="9"></td><td rowspan="9"></td><td rowspan="9"></td><td rowspan="9"></td><td rowspan="9"></td></tr>
<tr><td>Cadres dirigeants (nb)</td></tr>
<tr><td>Techniciens (nb)</td></tr>
<tr><td>Plongeurs et ex-pêcheurs (nb)</td></tr>
<tr><td>Femmes (nb)</td></tr>
<tr><td>Ouvriers (nb)</td></tr>
<tr><td>Accidents graves (nb)</td></tr>
<tr><td rowspan="2">Emplois indirects</td><td>Échelle nationale</td></tr>
<tr><td>Échelle Gouvernerat (Monastir)</td></tr>
</table>

<table>
<tr><th>Code</th><th></th><th>OUI</th><th>NON</th><th>En cours</th><th colspan="2">Si oui, préciser</th></tr>
<tr><td rowspan="2">INDGOUV_1</td><td rowspan="2">Existence de ZAA (Monastir)</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td>Années de préparation</td><td></td></tr>
<tr><td>Année de mise en place</td><td></td></tr>
<tr><td rowspan="4">INDGOUV_2</td><td rowspan="2">Existencede mécanismes participatifs dans les processus décisionnels</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td>Années de préparation</td><td></td></tr>
<tr><td>Année de mise en place</td><td></td></tr>
<tr><td rowspan="2">Degré des mécanismes de participation</td><td>Informative</td><td>Consultative</td><td>Décisionnelle</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Code		OUI	NON	En cours	Si oui, préciser	2008	2009	2010	2011	2012	2013	2014	2015	2016
INDGOUV_3	Existence de programmes de Recherche et Développement et de formation financés pour l'aquaculture				Valeur des fonds allouées									
INDGOUV_4	Existence d'une législation ou réglementation spécifique encadrant/relative au développement de l'aquaculture en accord avec les principes du CCRF (Code de conduite pour pêche responsable)				Années de préparation									
					Année de mise en place									
					Préciser l'article									

Code		OUI: Existence de systèmes de collecte et de diffusion de données	NON: Absence de collecte de données, de système de diffusion ou d'accessibilité	Existence d'une collecte mais absence de système de diffusion ou d'accessibilité
INDGOUV_5	Existence de systèmes de collecte et de diffusion de données			

Annex 5: Socioeconomic, administrative and legal, description of the area and environmental data needed. Status: red colour (non-available for the moment), yellow colour (in progress) and green colour (available). t: tonnes; DT: Tunisian dinar; cm: centimetres; .shp: file extention; µM: micromolar; m: meters; l: liter.

	Parameters	Details	Institution	Status
Socioeconomic	Production (t)	Per farms, year and species	CRDA-farmers	
	Production per zone (t)	Per home ports (3 in Monastir)	CRDA	
	Production cost (DT)	Per farm and year	CRDA-farmers	
	Profit (DT)	Per farm and year	CRDA-farmers	
	Unit price of the product (DT)	Per species, farm and year	CRDA-farmers	
	Average unit price of the food (DT)	Per farm and year	CRDA-farmers	
	Average unit price of the juveniles (DT)	Per species and year	CRDA-farmers	
	First sale location (coordinates)	Per farm (in ports, fish markets or others)	CRDA-farmers	
	Quality/safety certification systems	Per farm	CRDA-farmers	
	Size of sales units (cm)	Per farm and species	CRDA-farmers	
	Food conversion ratio	Per farm, species and year	CRDA-farmers	
	Percentage of value-added products	Per farm and species	CRDA-farmers	
	Import and export of fish (t and DT)	Per year, in Tunisia and in Monastir	CRDA-farmers	
	Aquaculture employees (direct and indirect)	Per farm and year, Tunisia and Monastir	CRDA-farmers	
	Fisheries employees (direct and indirect)	Per year, in Tunisia and Monastir	CRDA-farmers	
	Number of boats	Per port	CRDA-farmers	
	Fisheries production (t)	Per port, species and year, in Monastir	CRDA-DGPA	

	Parameters	Details	Source	Status
legal/governance	Aquaculture farmer organizations	Existence and degree of participation	DGPA	
	Traceability system and labelling	Existence	DGPA	
	Farmers union	Existence	DGPA	
	Participatory mechanism in decision process	Existence	DGPA	
	Current legislation for aquaculture		DGPA	
	Fish farmers/technical and scientists discussion	Number per year	DGPA	

	Parameters	Details	Source	Status
Description of the area	Coastline (.shp)	Tunisia/Monastir	DGPA	
	Wetland (.shp)	Monastir	DGPA	
	Home port for aquaculture	Location	DGPA	
	Bottom type and *P. oceanica*	Description and location	DGPA	
	Maritime routes (.shp)	Location	DGPA	
	Marine protected area	Location	DGPA	
	Land-based structures	Location	DGPA	
	Tourism (Hotels and beaches)	Location	DGPA	
	Fishing zones (coordinates)	Location	DGPA	
	Administrative division	Location	DGPA	
	Bathymetry (.shp)	Bay of Monastir	DGPA	
	Infrastructures	Location	DGPA	
	Emissary (coordinates)	Location	DGPA	
	Urban areas	Location	DGPA	
	Farms (coordinates)	Location	DGPA	

	Parameters	Details	Source	Status
Environmental	Environmental monitoring program (EMP)	Per farm	Farmers	
	Escapees (number)	Estimated for the Bay of Monastir	Farmers	
	Antibiotic and antifungal (kg/year)	Average per farm and year	Farmers	
	Currents and wind direction/velocity (cm/s)	Monastir	INSTM-CTA	
	Benthic community	Index or modifications	INSTM-CTA	
	Nitrites (µM)	In the bay (outside the AZE)	INSTM-CTA	
	Nitrates (µM)	In the bay (outside the AZE)	INSTM-CTA	
	Phosphate (µM)	In the bay (outside the AZE)	INSTM-CTA	
	Turbidity (m)	In the bay (outside the AZE)	INSTM-CTA	
	Chlorophyll a (mg/l)	In the bay (outside the AZE)	INSTM-CTA	
	Dissolved oxygen (%; mg/l)	In the bay (outside the AZE)	INSTM-CTA	

Annex 6. Environmental Quality Standards (EQS) for Mediterranean marine finfish farming based on the response of the experts to a Delphi questionnaire. Modified from Karakassis and Sanchez-Jerez (2012).

		SAFE LIMIT	CRITICAL LIMIT
NITRITE (mg/l)	SURFACE	0.2	1
	INTERMEDIATE	0.2	0.4
	DEEP	0.1	0.35
NITRATE	SURFACE	4	10
	INTERMEDIATE	2	8
	DEEP	2	6
PHOSPHATE	SURFACE	0.5	1.5
	INTERMEDIATE	0.3	1.5
	DEEP	0.3	1
TOTAL SUSPENDED MATTER (TSM) (mg/l)	SURFACE	7.5	50
	INTERMEDIATE	10	30
	DEEP	10	50
PARTICULATE ORGANIC MATTER (POM) (mg/l)	SURFACE	0.5	3
	INTERMEDIATE	5.5	9.5
	DEEP	1.5	5
Turbidity (m)		2-5m	1-2,5m
DISSOLVED OXYGEN (mg/l)	SURFACE	7	5
	INTERMEDIATE	6	5
	DEEP	5	4

El Máster Internacional en GESTIÓN PESQUERA SOSTENIBLE está organizado conjuntamente por la Universidad de Alicante (UA), el Ministerio de Agricultura, Alimentación y Medio Ambiente (MAGRAMA), a través de la Secretaría General de Pesca (SGP), y el Centro Internacional de Altos Estudios Agronómicos Mediterráneos (CIHEAM), a través del Instituto Agronómico Mediterráneo de Zaragoza (IAMZ).

El Máster se desarrolla a tiempo completo en dos años académicos. Tras completar el primer año (programa basado en clases lectivas, prácticas, trabajos tutorados, seminarios abiertos y visitas técnicas), durante la segunda parte los participantes dedican 10 meses a la iniciación a la investigación o a la actividad profesional realizando un trabajo de investigación original a través de la elaboración de la Tesis Master of Science. El presente manuscrito es el resultado de uno de estos trabajos y ha sido aprobado en lectura pública ante un jurado de calificación.

The International Master in SUSTAINABLE FISHERIES MANAGEMENT is jointly organized by the University of Alicante (UA), the Spanish Ministry of Agriculture, Food and Environment (MAGRAMA), through the General Secretariat of Fisheries (SGP), and the International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM), through the Mediterranean Agronomic Institute of Zaragoza (IAMZ),

The Master is developed over two academic years. Upon completion of the first year (a programme based on lectures, practicals, supervised work, seminars and technical visits), during the second part the participants devote a period of 10 months to initiation to research or to professional activities conducting an original research work through the elaboration of the Master Thesis. The present manuscript is the result of one of these works and has been defended before an examination board.